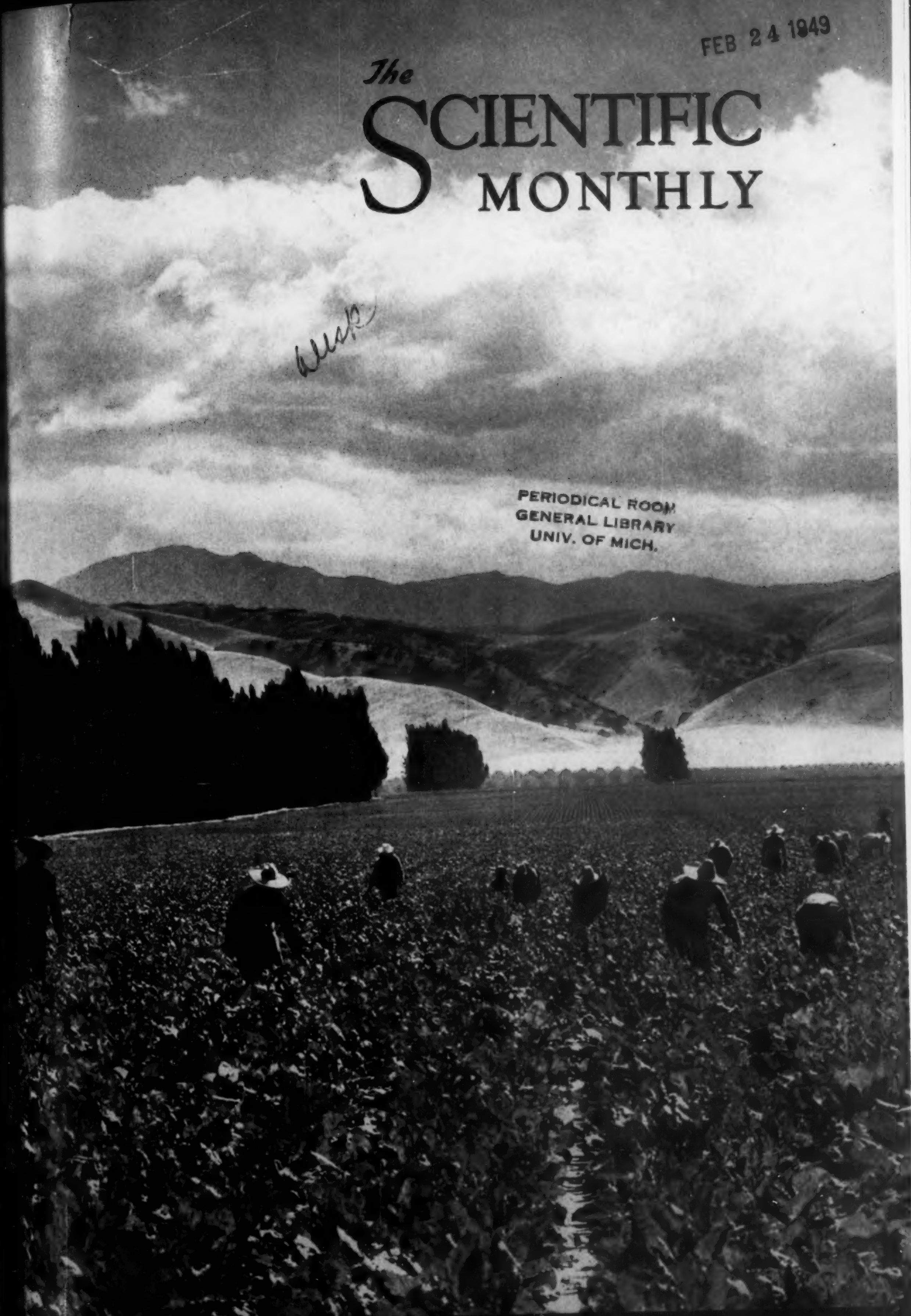
The SCIENTIFIC MONTHLY



LXVIII NO. 3 MARCH 1949


Radiation
Survey Meter
The Autoscaler
Laboratory Monitor
Thin Mica
Window Geiger Tubes
Automatic Sample Changer
With Lead Shield

THE SCIENTIFIC MONTHLY

VOL. LXVIII — MARCH 1949 — NO. 3

Contents

Publication office, Business Press, Inc., 10 McGovern Ave., Lancaster, Pa. Orders for subscriptions and requests for change of address should be directed to the Circulation Department, A.A.A.S., 10 McGovern Ave., Lancaster, Pa., or 1515 Massachusetts Ave., N.W., Washington 5, D. C. Subscriptions: $7.50 per year; single copies 75 cents. Four weeks are required to effect changes of address.

Address all correspondence concerning editorial matters and advertising to The Scientific Monthly, 1515 Massachusetts Ave., N.W., Washington 5, D. C. The editors are not responsible for loss or injury of manuscripts and photographs while in their possession or in transit; all manuscripts should be accompanied by return postage. The American Association for the Advancement of Science assumes no responsibility for the statements and opinions expressed by contributors.

 Entered as second-class matter at the Post Office at Lancaster, Pa., December 30, 1947, under the Act of March 3, 1879. Acceptance for mailing at the special rate of postage provided for in the Act of February 28, 1925, embodied in paragraph 4, Sect. 538, P. L. and R., authorized December 30, 1947. Indexed in the ***Reader's Guide to Periodical Literature.***

New Books Received

The Case of Augustus D'Esté. DOUGLAS FIRTH. 58 pp. $1.75. Macmillan. New York. 1948.

The Soul of the Universe. (2nd ed.) GUSTAF STROMBERG. xx + 312 pp. $3.50. McKay. Philadelphia. 1948.

Fundamentals of Psychoanalysis. FRANZ ALEXANDER. 312 pp. $3.75. Norton. New York. 1948.

Jane's All the World's Aircraft. LEONARD BRIDGMAN, Ed. Illus. $20.00. Macmillan. New York. 1948.

Crucibles: The Story of Chemistry. BERNARD JAFFE. xii + 480 pp. $3.95. Simon & Schuster. New York. 1948.

Newer Synthetic Analgesics. Annals N. Y. Acad. Sciences, Vol. 51, Art. 1, pp. 1–174. VARIOUS AUTHORS. $2.75. 1948.

Danger! Curves Ahead! MIRIAM LINCOLN. x + 138 pp. Illus. $2.50. Macmillan. New York. 1948.

The Book of Musical Instruments. PAUL NETTL. x + 381 pp. Illus. $5.00. Philosophical Library. New York. 1948.

The Shipwright's Trade. SIR WESTCOTT ABELL. xiii + 219 pp. Illus. $4.50. Cambridge Univ. Press. 1948.

The Chemical Arts of Old China. LI CH'IAO-P'ING. viii + 215 pp. Illus. $5.00. Journal of Chemical Education. Easton, Pa.

Health Instruction Yearbook 1948. OLIVER E. BYRD, Ed. ix + 320 pp. $3.50. Stanford Univ. Press. 1948.

Cathedrals and How They Were Built. D. H. S. CRANAGE. viii + 40 pp. Illus. $2.50. Cambridge Univ. Press. Cambridge, Eng. 1948.

A Source Book of Greek Science. MORRIS R. COHEN and I. E. DRABKIN. xxi + 579 pp. Illus. $9.00. McGraw-Hill. New York. 1948.

4,000 Years of Christmas. EARL W. COUNT. 91 pp. $2.00. Henry Schuman. New York.

Science at War. J. G. CROWTHER and R. WHIDDINGTON. 185 pp. Illus. $6.00. Philosophical Library. New York.

Practical Spectroscopy. G. R. HARRISON, R. C. LORD, and J. R. LOOFBOUROW. xiv + 605 pp. Illus. $6.65. Prentice-Hall. New York. 1948.

Indian Art. H. G. RAWLINSON, K. DE B. CODRINGTON, J. V. S. WILKINSON, and JOHN IRWIN. 200 pp. Illus. $3.75. Philosophical Library. New York. 1948.

Overweight is Curable. WILFRED DORFMAN and DORIS JOHNSON. viii + 150 pp. $2.75. Macmillan. New York. 1948.

Mineral Nutrition of Plants and Animals. FRANK A. GILBERT. $2.75. xii + 131 pp. Illus. Univ. of Oklahoma Press. Norman. 1948.

The Universe and Dr. Einstein. LINCOLN BARNETT. 127 pp. Illus. $2.50. Sloane Associates. New York. 1948.

The Science of Biology Today. TROFIM LYSENKO. 62 pp. $1.25. International Pub. New York. 1948.

Atlantic Reef Corals. F. G. WALTON SMITH. 112 pp. + 41 plates. $3.75. Univ. of Miami Press. 1948.

A Hundred Years of Chemistry. (2nd ed.) ALEXANDER FINDLAY. 318 pp. $4.50. Cambridge Univ. Press. New York. 1948.

Factors in Botanical Publication and Other Essays. NEIL E. STEVENS. 88 pp. $2.00. Chronica Botanica. Waltham, Mass. Stechert-Hafner. New York. 1948.

The Fig. IRA J. CONDIT. xviii + 122 pp. Illus. $5.00. Chronica Botanica. Waltham, Mass. Stechert-Hafner. New York. 1948.

Fear, War, and the Bomb. P. M. S. BLACKETT. vii + 244 pp. $3.50. Whittlesey House. New York. 1949.

An Introduction to Mathematics. A. N. WHITEHEAD. v + 191 pp. $2.00. Oxford Univ. Press. New York. 1948.

Bird Display and Behaviour. EDWARD A. ARMSTRONG. 431 pp. Illus. $5.50. Oxford Univ. Press. New York. 1948.

Carl Alsberg, Scientist at Large. JOSEPH S. DAVIS, Ed. xi + 182 pp. $2.00. Stanford Univ. Press. 1948.

Ice Fishing for Everybody. BYRON W. DALRYMPLE. 257 pp. Illus. $3.50. Lantern Press. New York. 1948.

Sex and Religion. PIERRE GORDON. 320 pp. $5.00. Social Science Pub. New York. 1949.

Chemistry and Uses of Insecticides. E. R. DE ONG. viii + 345 pp. $6.00. Reinhold. New York. 1948.

Refrigeration and Air Conditioning. RICHARD C. JORDAN and GAYLE B. PRIESTER. xv + 512 pp. Illus. $7.75. Prentice-Hall. New York. 1948.

Survey of Food and Nutrition Research in the United States, 1947. COMMITTEE OF THE NATIONAL RESEARCH COUNCIL, Frank G. Boudreau, Chairman. ix + 306 pp. $1.00. National Research Council, July 1948. Washington, D. C.

Science Outpost. JOSEPH and DOROTHY NEEDHAM, Eds. 313 pp. Illus. 25*s*. Pilot Press. London, Eng. 1948.

Aureomycin—A New Antibiotic. ROY WALDO MINER, Ed. 168 pp. Illus. $2.50. Annals N. Y. Acad. Sciences. 1948.

How to Live Longer. JUSTUS J. SCHIFFERES. 255 pp. $3.00. Dutton. New York. 1948.

Wild Animals of the World. MARY BAKER and WILLIAM BRIDGES. 272 pp. Illus. $4.95. Garden City Pub. New York. 1948.

Mirror for Man. The Relation of Anthropology to Modern Life. CLYDE KLUCKHOHN. xi + 313 pp. $3.75. Whittlesey House. New York. 1949.

Film Education. GODFREY M. ELLIOTT, Ed. xi + 597 pp. $7.50. Philosophical Library. New York. 1948.

The Earth and Man. A Human Geography. (Rev. ed.) DARRELL HAUG DAVIS. xxiv + 696 pp. Illus. $5.50. Macmillan. New York. 1948.

Your Coughs, Colds and Wheezes. JOSEPH D. WASSERSUG. viii + 277 pp. $2.95. Wilfred Funk. New York. 1949.

Inorganic Preparations. A Laboratory Manual. HAROLD FREDERIC WALTON. viii + 182 pp. $4.00. Prentice-Hall. New York. 1948.

Reconnaissance of the Geology and Oil Possibilities of Baja California, Mexico. CARL H. BEAL. x + 138 pp. Illus. Geological Society. New York. 1948.

Cation Exchange in Soils. WALTER P. KELLY. xiii + 144 pp. $4.50. Reinhold. New York. 1948.

Scientists and Amateurs. A History of the Royal Society. DOROTHY STIMSON. xiii + 270 pp. Illus. $4.00. Henry Schuman. New York. 1949.

Handbook of Uranium Minerals. JACK DEMENT and H. C. DAKE. 96 pp. Illus. $2.00. Mineralogist Pub. Co. Portland, Ore. 1948.

Basic Principles of Psychoanalysis. A. A. BRILL. xv + 298 pp. $3.45. Doubleday. New York. 1949.

Stratigraphy and Fauna of the Agua Salada Group, State of Falcón, Venezuela. H. H. RENZ. x + 219 pp. Illus. Geological Society. New York. 1948.

Treason Complex. RENE ALLENDY. 208 pp. $3.75. Social Sciences Pub. New York. 1949.

science
has bee
purest
Nor
launchi
crisis h
beginni
petition
around
to mai
peting
situatio
the pro
have di
crop; c
esses of
diseases
through
possible
New
wartime
Highly
sugar b
importa
our peo
munitio
by-proc

THE SCIENTIFIC MONTHLY

MARCH 1949

THE SUGAR BEET: PRODUCT OF SCIENCE

GEORGE H. COONS

Dr. Coons (Ph.D., Michigan, 1915) is principal pathologist in charge of research on sugar beets, Division of Sugar Plant Investigations, Bureau of Plant Industry, Soils and Agricultural Engineering, ARA, USDA, Beltsville, Maryland.

THE creation of the sugar beet out of the lowly mangel-wurzel is a triumph of plant breeding. Through the miracles of modern science, sugar, once the luxury of the very rich, has been transformed into one of the cheapest and purest of foods, available to all.

Nor did the demands on science end with the launching of beet-sugar enterprise, for crisis after crisis has confronted the new industry. From the beginning, sugar from the sugar beet was in competition with tropical and subtropical sugar. Even around the factory itself, the sugar beet has had to maintain itself against other crop plants competing for the farm acreage. To cope with such situations, plant breeders have constantly increased the productivity of the sugar beet; agronomists have discovered efficient methods of growing the crop; chemical engineers have improved the processes of sugar manufacture; and against epidemic diseases resistant varieties have been bred. Only through these contributions of science has it been possible for the sugar beet to survive.

New problems face the sugar industries. The wartime sugar situation is fresh in our minds. Highly important in our economy in time of peace, sugar becomes, in time of war, of prime strategic importance. It is a necessity as food for our armies, our people, and our allies. In the manufacture of munitions and strategic materials, sugar and its by-products are essential. Sugar was among the first commodities rationed and the last off the list. In wartime, domestic production of sugar takes on especial significance. Grown within our borders, this sugar is safe from enemy submarines, and every ton produced at home, be it from mainland sugar cane or from the sugar beet, reduces by just that much the demands on maritime shipping. In a troubled world, there are potent reasons why our domestic sugar industries must be maintained.

In the few years since the close of the war, scarcity of sugar has almost turned to excess, a situation brought about in part because nations lack dollars to buy the very foodstuff they crave. World surpluses of sugar may bring economic problems of great magnitude to the industry as a whole, and these threaten the sugar-beet industry of this country. What has been so painstakingly built up appears now to be threatened unless production costs, already low, can be further reduced. This is the road to survival for the sugar beet. The industry turns to agricultural science for ways and means of accomplishing this. By intensified research better varieties and strains must be discovered, and these must be grown and processed in the most efficient ways. The chance of success in meeting this new appeal for help may, in some degree, be gauged by review of what sugar-beet research has accomplished and by appraisal of its armamentarium of scientific methods, techniques, and plant materials.

SUGAR AND THE SUGAR BEET

Sugar of commerce and the kitchen is sucrose. It is purchased as practically a chemically pure product. Obviously, *sucrose*, the chemical, is the same irrespective of the plant from which it is obtained. Impurities are so negligible in amount that for all ordinary uses beet and cane sugar are interchangeable. The United States is the world's largest user of sugar, consuming annually about 100 pounds per capita, which amounts to a little over 7,000,000 tons. Sugar is used directly as a food and in baked goods, confectionery, canned goods, preserves, soft drinks, etc. It has countless uses and applications in pharmacology, industry, and the arts. Nearly 25 percent of the sugar used in the United States is supplied by our sugar-beet industry.

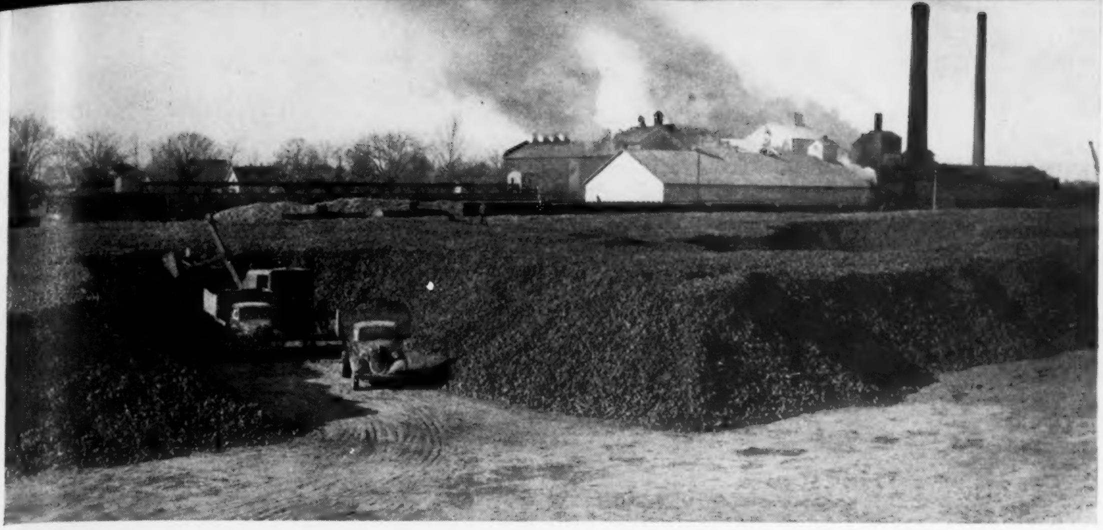
The sugar beet is a Temperate Zone crop. It is grown in Europe, Asia, Australia, and in North and South America. In Europe, beet sugar is an article of international trade and is grown from Gibraltar to the Arctic Circle. It is grown in the USSR, both in Europe and in Asia; in Turkey, Afghanistan, and Iran; in Korea, Manchuria, and Japan. Culture in north-central China is a possibility. There is one factory in Australia. In the Western Hemisphere, culture of the sugar beet is chiefly in the United States and Canada, although Argentina once grew sugar beets on a small scale in the Rio Negro Valley. Trials to determine whether the crop will be an economical source of sugar are under way in Chile. Beet sugar production is established in Uruguay.

Acreage planted to sugar beets in the United States has in some years exceeded 1,000,000 acres. In 1948 the area for harvest was estimated at 700,000 acres. The crop is grown in 22 states, of which California, Colorado, Idaho, Michigan, Montana, Nebraska, and Utah are the leading producers.

The average acre yield of the sugar beet in the United States is about 12.5 tons. Since about 15.5 percent of the root weight is sucrose, the average acre yield of sugar amounts to nearly 2 tons. As a producer of calories, the sugar beet stands high among all crop plants, outranking corn and the small grains in digestible nutrients produced. From the roots, sugar is obtained as the main product, with beet molasses and beet pulp as by-products. In addition, the leaves and crowns, called sugar-beet tops, are left on the farm and constitute a valuable livestock feed. An average crop will supply the farmer about 4 or 5 tons of tops for forage. Yields of sugar-beet roots run far above the national average in those states having especially favorable conditions of soil and climate; for example, California crops often average 18 tons per acre, and Colorado, 16 tons. A yield of roots of 65 tons per acre has been reported for California, but the sucrose quality was low. An outstanding production record came from a 150-acre tract near Salinas, California, that averaged 37.5 tons of roots per acre with a 19.91 percent richness in sucrose, corresponding to a yield of nearly 7.5 tons of pure sugar per acre.

Sugar-beet seed is planted in a carefully prepared seedbed in early spring. The rows are usually 20–24 inches apart, and a fairly dense seeding is made. The initial close stand of seedlings is

Sugar-beet root of good type.



Beet-sugar factory. Roots in the storage piles represent only a portion of the total to be processed. (From the E. E. Patton collection, courtesy of Mrs. Emily Patton Colmus.)

thinned to leave single plants standing 10–12 inches apart in the row. The sugar-beet farmer seeks to retain a population of about 25,000 plants evenly distributed over an acre. By August, the leaves cover the ground and the rows can hardly be distinguished. A vast array of gray-green, glossy leaves presenting a million living surfaces to trap sunshine, a field of healthy sugar beets is an inspiring sight. By mid-October the crop is made, and the long, cone-shaped roots are ready for harvest. These run from 1 to 2 pounds up to 5 or more pounds in weight—root size being dependent on stand, soil fertility, soil moisture, length of season, freedom from wasting disease, and other factors. Among all plant forms, the sugar beet is unique because it stores in its roots such high amounts of pure sucrose. Anywhere from 12 to 22 percent of the fresh weight of the root may be sucrose. Other sugars, such as dextrose, are negligible in amount. As with root size, the quality of the root is a function of the conditions of growth.

A strictly biennial type of sugar beet is desired for culture. In the first year of growth, foliage and root are formed; if the roots are held over winter, then in the second year the plant sends up stalks on which the seed balls are borne. These are glomerules formed by the fusion of florets. A seed ball may contain one, two, or many true seeds. Botanically, the sugar beet is *Beta vulgaris* L., as are also the red garden beet, chard, mangel-wurzel, and the sea beet, commonly called *B. maritima,* found growing wild along the Mediterranean and Atlantic shores of Europe. Thus we have within this species the red beet, the garden vegetable with its purple-red, globose root; the mangel-wurzel, with its tankard or cowhorn-shaped root, red-, pink-, or yellow-fleshed; Swiss chard, the salad plant, whose small, sprangled root seems only to serve as a base for the green or red-colored, engorged leaves; and *Beta maritima,* the presumptive wild progenitor of the species, beetlike in character, but with thickened leaves and small, sprangled root. Allied to these forms, but entirely distinct in form and function, is the sugar beet. Its leaves are green or only tinted or veined with red. The root is long, obconical, or parsnip-shaped. Its flesh is white, never colored, and its skin is white or creamy. The sugar-beet root does not extend out of the ground as does that of the mangel-wurzel, but seems to nestle in the soil. All varieties of *B. vulgaris* readily intercross.

CREATION OF THE SUGAR BEET

Origins of most of our important crop plants are lost in antiquity. Over countless centuries, primitive man preserved his food plants, intuitively selecting them for improved form and function. They come to us as a legacy of the past, and we can only speculate as to the primitive types. In contrast to this, the origin of the sugar beet is known, and the research that gave it to us is a matter of record.

The discovery that sucrose, until then known only as palm or cane sugar, exists in plants endemic to Europe was made in 1747 by Andreas Siegmund Marggraf, director of the Mathematical-Physical Class of the Royal Prussian Academy of Science. This great chemist, protégé of Frederick the Great, found sucrose in *Beta alba* (presumably chard), in *Beta rubra,* the red beet, and in *Sium sisarum,* the skirret. This was not a mere recording of sweetness, as had been done a century before, but actual recovery of sugar from the juice by crystallization.

Nowadays, we take the trade in sugar as a matter of course, but for centuries sugar and other exotic products were the prized commodities of world trade. Nations contrived, struggled, plotted, and fought for trade supremacy. Trade with the

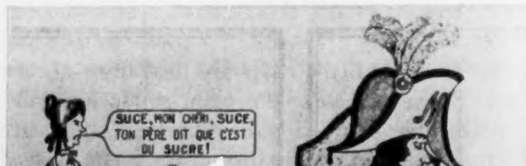
Indies through Asia Minor before the fall of Constantinople made the greatness of Venice, Pisa, and Genoa; the search for a new route to the Indies motivated the voyages of Columbus; "spices of the Orient," to use the intriguing phrase of our schoolbooks, were widely sought. But these were more sugar than spice. Columbus himself on his second voyage brought sugar cane from the Canary Islands to the New World. A century or two later America was to wrest from the Indies the trade in sugar.

When Marggraf made his discovery, France and England were engaged in a great struggle for mastery of colonial trade in which sugar, rum, and tobacco—the products of plantations worked by African slaves—were exchanged for the manufactures of Europe. Frederick the Great was building in Prussia the intense spirit of nationalism. Against this background Marggraf made his discovery, and he boldly announced that "This sweet salt, sugar, may be made as well from our plants as from sugar cane." It remained for Marggraf's pupil and successor in the Prussian Academy of Science, Franz Carl Achard, to bring to fruition the dream of the old chemist.

After the death of Marggraf in 1782, Achard became leader of the Physical Class of the Academy of Science (1786). He investigated to the high satisfaction of Frederick the Great and his successor, Frederick William II, various problems of chemistry, physics, and agriculture. The first experiments with beets as a source of sugar began in 1784, two years before the death of Frederick the Great. In the next decade, the supply of raw sugar to Prussian refineries became more and more uncertain and the price went higher and higher. In 1799 Achard received a grant from Frederick William III, then King of Prussia, that permitted him to devote his full time to improving the beet as a source of sugar and to finding processing methods. We may safely assume that Achard was fortified by his faith in Marggraf's discovery, by his own experiments, and by his knowledge that the peasants of the Magdeburg region had for generations made a sweet syrup from beet roots.

It was Achard's task to start with the beet complex as it existed on farms and gardens around Magdeburg and from this motley of types find those plants that contained a high amount of sucrose and only low amounts of compounds that interfere with recovery of sugar. When the usable sugar plant was found, proper methods of culture to give both root size and quality had to be discovered, and then practical methods of extraction, purification, and crystallization of sugar had to be devised. As a starting point Achard chose from some 26 varieties he had collected the *Runkelrüben* of the Magdeburg peasants. Probably its nearest relative today is the mangel-wurzel. The stocks available were a mixture of red-, white-, and yellow-fleshed plants extremely variable in shapes and sizes. By a masterly job of plant breeding Achard found the types richest in sugar and purified them. He compared and tested methods of culture, and wrote a practical guide on beet growing. To agriculture he contributed the White Silesian beet denominated by von Lippman, the historian, "as ancestress of all the sugar beets of the world."

It would be a pleasant excursion to explore fully the historical background of this development of the sugar beet as a Temperate Zone source of sugar. Here was a potential rival of sugar cane. The royal support given Achard's research shows the Prussian hope of becoming independent of imports from the plantations of French, Spanish, and English colonies. But our story must move more swiftly, and we may only set down that this great pioneer bred a fairly high-yielding and moderately sweet beet that for the first time was called sugar beet, and that he discovered in his little sugar factory at Cunern, Silesia, the methods for making sugar from it. These methods were forerunners of those used today in the great sugar factories that take advantage of every advance in chemical engineering. The record clearly shows that this brilliant scientist learned to grow the crop, developed processes for sugar extraction, purification, and crystallization, established breeding and seed production programs, taught students his methods and techniques, and by his publications made his discoveries the property of the



Contemporary cartoon satirizing Napoleon's attempt to establish a sugar-beet industry.

Sugar-beet seed field in Oregon. (Photo by Geo. T. Scott.)

world. Achard is universally recognized as the father of the beet-sugar industry.

That Achard's factory burned to the ground in 1807; that in the troublous period of the Napoleonic Wars he could not get funds to rebuild; that continuance of the industry in Prussia and the saving of the White Silesian beet for agriculture depended on Freiherr von Koppy, friend and follower; that Achard died in 1821, poor, unknown, and unrecognized for his contributions, make his life conform to the pattern the world so often contrives for its benefactors.

Because of far-reaching effects upon the launching of the beet-sugar industry, we need to relate the story to Napoleon's continental system which forbade any trade with England. Historians have dwelt on the paralyzing effects on the life of Europe that cessation of maritime trade brought about. Sugar refineries of continental Europe that had worked raw sugars of the tropics were idle. Everywhere there was a dearth of sugar. In the emergency, Napoleon seized on Achard's discovery and ordered beet sugar to be made in France. By his decree of March 25, 1811, he subsidized the establishment of beet-sugar factories. Hundreds sprang up, and the sugar beet was launched in France as a new crop. The discoveries of Achard, almost without notice at home, were the foundation of the French industry. A cartoon appearing at about this time shows derisive political comment on the project.

EARLY WORK OF BREEDING SUGAR BEETS

In the first quarter of the nineteenth century, when the sugar beet began to be utilized as a sugar source, the root yields of the White Silesian beet were probably not more than a few tons per acre, and sucrose percentages were probably not over 7 or 8 percent. Philippe-André de Vilmorin, of the famous breeding establishment of France, began selection work based on morphological characters about 1820. The record is obscure, but some improvements were made. In the late twenties and thirties the sugar-beet industry entered into very hard times. The industry failed in France and disappeared in Germany, only to be revived about 1840 with the introduction of the Imperial beet. This sugar-beet variety was a stronger grower and higher in sugar than the White Silesian from which it undoubtedly was derived. It gave new impetus to home production of sugar because it strengthened the weak part of the program, namely, agricultural production. Beet-sugar factories sprang up everywhere in central Europe. Sugar-beet culture was a boon to the run-down fields where a long succession of grain crops had made the soil foul with weeds, destroyed tilth, and created an unbalanced condition in soil nutrients. As a cultivated row crop it broke the retrograde sequence, and its by-products encouraged livestock farming. Agricultural economists attribute to the sugar beet the revival of agriculture.

A heavy yield of sugar-beet seed curing in shocks before threshing, St. George, Utah. (Photo by Bion Tolman.)

A great contribution to the science of plant breeding was made in France by Louis de Vilmorin, son of Philippe-André. In his researches to improve sugar beets, Louis discovered the significance of the progeny test as a means of judging the breeding potential of plants. He was the first to give continued attention to individual selection. This discovery, which now seems so very simple and, when viewed by hindsight, almost axiomatic, is fundamental in plant genetics. Vilmorin, in his improvement of the sugar beet, did not judge a selected plant by its size or its analysis, but by its potency in contributing these factors to its progeny. He developed ingenious tests to determine ease of lifting the beet—since apparently sugar beets with long, slender roots were sweeter—and gravimetric methods whereby sugar beets could be appraised for sweetness. Saillard is authority for the statement that he employed the polariscope as early as 1853 to determine richness in sucrose. Running through his researches was the cardinal principle of judging the breeding value of a plant by its progeny.

Within a decade, improvement of the sugar beet by application of Vilmorin's new technique was given further impetus by the rather general employment of the polariscope to determine the sucrose percentage of individual roots as a basis for discriminating selection. Here was a precision instrument that immediately showed the quality of a root, a determination by other means of analysis requiring hours. The way was open for highly efficient selection for sucrose content. Accordingly, by 1875, or even earlier, sugar beets were obtained by mass selection from the old White Silesian stock, either by way of the Vilmorin strains or the Imperial, that in sucrose percentage and perhaps in productiveness approached those we grow today.

MASS SELECTION

There sprang up on the continent of Europe a number of sugar-beet breeding establishments that employed the mass-selection system. Progeny tests constituted the guiding principle in the breeding program. The method of breeding used has been called mother-line breeding. In principle it does not differ from the "ear-to-row" system that at one time was the mainstay of corn breeding. A mother beet was selected and brought to seed along with other selectees. Although some isolation was attempted, for the most part selected individuals pollinated *inter se*. Then a portion of the seed from each mother plant was used in tests to determine the progenies giving the best performances in sucrose percentage, in root size, or in sugar production. For example, seed lots that were produced on the mother plants whose progenies were found highest in sugar were then individually increased in small parcels more or less isolated. The selection process and lining went on year after year, with selections being made from pedigreed stocks—pedigreed so far as the mother was concerned. Breeders spoke of the method as family breeding, and certain beets, always the mother beet, were denominated "heads of families."

Each establishment produced its own brand of sugar beet. It is to be expected that any outstanding advance by one establishment led to subsequent appropriation of a superior stock, either for direct use under a new name or for amalgamation into a general pool. Various claims were made by the breeding establishments as to what their meth-

ods were accomplishing. The only identifiable thread in the breeding history was the mother beet, whose selection was based on the qualifications of her progeny. This mother beet had been subjected to pollination by a great number of other roots similarly under test; the progeny was therefore not a selfed one, but a congerie of hybrids. Furthermore, a mother beet must have produced a heavy set of seed or it was dropped. Heavy seed production in the sugar beet almost always implies cross-fertilization. It seems clear that progenies tested were hybrids; hence, the only distinctive characteristic of a progeny was the fact that the plants had the mother in common. Any selection from the material at a breeding establishment would essentially be selection of F_1s, and these subsequently were allowed to interpollinate. The postulated continuance, generation after generation, of hereditary characters from a given mother that once was head of a family obviously did not take place. What did take place was a slow but probably continued mass selection toward a target of either high sucrose percentage or high productivity, since it is entirely probable that these strong physiological differences could, by the methods employed, guide selection. As these types were established and the so-called high-sugar families began to be kept distinct from high-yield families, a selection would produce more decisive winnowing out of aberrant, or nonconforming, types. As a result, sugar-beet breeding establishments of continental Europe, all following the same methods of selection, offered in the period 1890 to date relatively fixed physiological types—high-sugar (*Zucker,* or "Z"), high-yield (*Ernte,* or "E"), and a compromise type (*Normal,* or "N")—the last-named being the catchall group into which stocks not falling within other types were bulked.

No disparagement of the European methods that gave us the sugar-beet stocks used for over seventy-five years, and on which the sugar-beet industry of the world was founded, is intended by the above critique. By slow process, the "varieties," or brands, of sugar beet were produced that, under normal conditions of growth, were high-yielding, extremely sweet, and a distinct contribution to agriculture. The textbooks on plant breeding at the end of the nineteenth century cite the meticulous efforts of the sugar-beet breeder as exemplifying proper applications of the breeder's art.

Schribaux' graph showed that in the period 1838–68, with morphological selection, the average richness (sucrose percentage) progressed from 8.8 to 10.1; in the period 1868–88, to 13.7 percent; and in the period 1888–1912, to 18.5 percent. Schneider cites similar comparisons, by periods, drawn from the agricultural and factory statistics of Germany, but he calls attention to low recovery of sugar in the earlier periods of the industry—factory inefficiency being interpreted as the result of low-quality sugar beets. Bonne cites records from a sugar-beet breeding establishment that show a gradual climb in sucrose percentage from an average 16 percent in 1883–87 to about 23 percent in 1930.

There is evidence from tests run in the United States in the period 1880–1900 that the various European varieties of sugar beet commonly produced 10–20 tons of beets per acre, depending on agricultural conditions, and 12–18 percent sugar. The results of the various tests, many of which were conducted under the leadership of Dr. Harvey W. Wiley, famed chemist of the Department of Agriculture, read very much as do tests undertaken with European varieties today. There have been improvements. They are not the decade-by-decade increases commonly postulated; however, the data do prove that increased factory efficiency and an improved crop plant operated jointly to bring very definite advances in sugar production.

THE SUGAR BEET IN AMERICA

Early history of the industry in the United States is a record of one failure after another, as enthusiasts attempted to attain in America the success that the sugar beet was winning in Europe. The first factory was started in Northampton, Massachusetts, in 1837. After three years the venture was abandoned. Other attempts in a number of states likewise were failures. Of great interest was the attempt made by the Mormons in 1853 to establish the industry in Utah. This dramatic story, finally to be crowned by success nearly forty years later, is told by Taylor in his *Saga of Sugar.* The first successful factory in the United States was that at Alvarado, California, established in 1870, rebuilt in 1879, and finally modernized in 1936.

The entire history of the sugar beet in the United States is replete with instances of factories being established only to fail for one reason or another. By 1890, 16 factories had been erected and 13 removed, leaving 3: at Alvarado and Watsonville, California, and Grand Island, Nebraska. By 1900 the score stood: factories built, 50; removed, 16; existing, 34. By 1920, 146 factories in all had been erected, 42 had been removed, and 105 were left. By 1940, a total of 164 had been built, 67 removed, and 97 standing. In 1948 there were, in all, only 85 factories, located in 16 states, and

owned by 22 beet-sugar processing companies. Of these, 11 were scheduled as not operating in the 1947–48 campaign. The history of factories built and factories left is illustrative of the difficulties that this industry has faced as it has won its way in America.

Until a relatively recent period, the sugar beets grown were the product of European breeding establishments. In spite of early recommendations of Dr. Wiley and other scientists of the Department of Agriculture, and the clear showing in the period 1890–1900 of advantages from homebred varieties and home-grown seed, the industry, dominated by the European technologists brought over to run the sugar-making equipment, insisted on importing seed. This seed was capable of giving good crops under conditions comparable to those of Europe, but in the districts where the industry was struggling to become established the conditions were often decidedly different from those of Europe. As we shall see, the use of imported seed was at the bottom of much of the trouble of American factories.

In 1914, when war with Germany broke out, continental European ports were blockaded by the British fleet. This created an emergency for our beet-sugar factories because seed to plant the crop had to come from European breeding establishments. Arduous diplomatic representations finally obtained permission for German seed to come through the cordon—the seed to be consigned to the Chief of the Bureau of Plant Industry, who could release seed only when bond was given that the seed would not be transshipped. A prerequisite on the German side of the transaction was that the payment be in gold and that bond be given that the gunny sacks would be returned. In wartime, jute may be more important than money. In 1918 America, cut off from German seed sources, began to grow its own stocks as straight increases of European varieties. Eventually, the sugar-beet industry was able to produce almost enough seed to plant its acreage. Production followed the conventional European methods of growing roots in one season, storing them over winter in pits or silos, then transplanting the roots in the spring to produce seed. The job was expensive, and seed yields were uncertain. An estimated average yield of 500 pounds of seed per acre is probably liberal. As soon as trade was resumed after the war, the factories went back to importing sugar-beet seed.

Thus there was continued the anomalous situation of a great agricultural industry dependent on foreign sources for the seed from which to grow its crop. The World War I experience should have taught the disastrous effects of such dependence, but the lesson was soon forgotten because of the greater convenience and lower cost of foreign-grown seed.

EPIDEMIC DISEASES OF SUGAR BEET

In this period, it was the common experience for factories established in high hope to run a few years and then fail because recurrent outbreaks of disease meant either no sugar-beet roots to process or that the roots were of such low quality as to be unprofitable to work. Farmers would not grow a crop that was not dependable, and the factory would be forced to close. As the record shows, many beet-sugar factories had become almost gypsies, being moved from one place to another always in the hope of finding a favorable district where production would be stable.

Curly top is an especially serious disease of sugar beet and other crops. By 1926, it had caused repeated failures of the sugar-beet crop in the states west of the Rocky Mountains. Abandonment of factories in the West was entirely attributable to the ravages of curly top.

The disease is caused by a virus carried to beet fields by the beet leaf hopper (*Circulifer tenellus*), an insect that breeds on mustards, Russian thistle, and other weeds. Overgrazed rangelands were invaded by these weeds, so that vast tracts of the semiarid West became breeding grounds for the leaf hopper. Even more serious in furnishing breeding grounds were the abortive attempts during World War I at grain farming on plowed rangelands near irrigated districts. The native grass cover was destroyed, and, when the fields were abandoned, they became covered with almost solid stands of the weeds that were host plants for the insect. Enormous populations of the beet leaf hopper were bred on these weedy tracts. When the vegetation began to dry in the spring the leaf hoppers moved to the young beet plants in the fields in the irrigated valleys. Many of the insects carried curly-top virus, and the plants on which viruliferous hoppers fed became infected with curly top. Other leaf hoppers picked up the virus from these plants and carried it about so that soon no plant in the field escaped the disease! European varieties of sugar beet succumbed almost completely. The leaves curled, and growth of top and root almost stopped. In years of epidemic the havoc from the disease was clearly evident in late spring. Around factories, thousands of acres of sugar beets were plowed up for replanting to other crops or simply were abandoned.

As counterpart to epidemics of curly top in

sugar-beet districts west of the Rocky Mountains the more eastern producing areas were subject to sporadic epidemics of leaf spot. This disease, caused by a fungus, *Cercospora beticola,* blights the tops and causes dwarfing of root growth and depression of sucrose percentage. Its effects are less dramatic than curly top but no less damaging to the sugar-beet industry. The disease is a wasting one that reduces tonnage and sucrose enough to make the beet crop unprofitable both to farmers and factory. Years of outbreak are those in which in the early part of the season rainy periods are frequent and total precipitation abundant. Paradoxically, the very conditions that should give a bumper crop bring only disappointment as wave after wave of blight occurs. In epidemic years leaf spot may kill back the entire foliage bouquet several times in the growing season. New growth is pushed out, only to be blighted in two or three weeks. Replacement of blighted foliage by the new growth is at the expense of the root growth and sugar storage; hence a blighted crop is lacking in both weight and quality. The farmer has a short crop to harvest, and the factory has low-grade roots to process that cannot yield a profit. In the period 1915–30 blight years recurred frequently. Factories in the humid area and in other districts subject to leaf spot were in financial distress.

BREEDING FOR DISEASE RESISTANCE

In 1925 direct attack against curly top and leaf spot by disease-resistant breeding was started in the Bureau of Plant Industry. The program involved search for new genes by making collections of the wild progenitors of the sugar beet, selection of resistant types within the existing commercial varieties and strains of sugar beet, and the setting up of field stations at locations where severe exposures could be expected each year, to permit discriminating reselections.

Curly-top-resistance tests in agronomic plots at Castleford, Ida., photographed Sept. 19, 1930, by Eubanks Carsner. *Left foreground* (plot 1703): four rows of U. S. No. 1 variety; *right* (plot 1704): four rows of the nonresistant European brand (Pioneer), which are continuous through the field. Photograph shows also replicated plots of the U. S. No. 1 variety and those of three other resistant strains being tested.

In sugar-beet fields where curly top is severe, no plant escapes infection. Susceptible plants suffer very drastic effects, but a few plants—possibly 1 or 2 per 10,000—are outstanding because they show less severe reactions. Selection of these individuals from fields that had been severely attacked gave progenies that were more resistant than the general run. A combination of the best of such selections, plus roots from other sources having more or less resistance, gave rise to U.S. No. 1, the first curly-top-resistant variety of sugar beet, bred by Carsner, Pack, and their associates. *Achievement Sheet 78 P* of the Agricultural Research Administration tells how U.S. No. 1 held the line and gave new hope to the industry in the grave period when sugar-beet culture in the West was about to be given up.

U.S. No. 1, the curly-top-resistant variety, first became available for commercial use in 1933, and it was followed in 1935 by U.S. 34 and U.S. 33, reselections from it. The latter was selected for increased curly-top resistance and for high sucrose as well. For many years it was the standard variety for western United States. In 1938, U.S. 12, a reselection, and in 1940, U.S. 22, both varieties showing improvement over the earlier ones, were released. The resistant sugar beets have brought about most dramatic changes in the Western agricultural situation. The sugar beet became a dependable crop. Districts once abandoned for its culture now returned to full-scale production. The factory at Toppenish, Washington, was rebuilt on the foundations of the factory that had been given up and torn down because of curly top. Other factories have entered areas previously considered unsafe because of curly top. By 1938 the Western beet fields were planted almost exclusively to U.S. curly-top-resistant varieties, and a seed enterprise to supply domestically grown sugar-beet seed had sprung up. This was the first fruit of sugar-beet breeding projects.

Control of sugar-beet leaf spot could not be accomplished by mass selection. Nowhere in blighted fields did individual plants show themselves as outstanding in resistance. Furthermore, beet leaves as they become mature and moribund are subject to attack by leaf spot. This made recog-

Curly-top-resistance breeding field near Twin Falls, Ida., showing contrast between resistant and susceptible types. Portion of field left of arrow was planted April 11; right of arrow, May 1. Susceptible European variety (Old Type) is in center, flanked by the highly resistant variety U. S. 22.

nition of potentially valuable individuals almost impossible. When disease-resistance breeding began in 1925, there was available at Fort Collins, Colorado, as a result of many years of endeavor of the veteran breeder W. W. Tracy, a large array of sugar-beet strains, separated out from various sugar-beet accessions. Tracy's assignment was to break the sugar-beet complex into its components on the basis of morphological characters.

When about 200 Tracy strains were grown in 1925 at Rocky Ford, Colorado, under conditions of severe leaf-spot exposure and judged for leaf-spot resistance, 14 strains were noted as outstanding. All others had blighted severely, but these remained relatively green. Leaf spot that season also made a relatively severe attack at Fort Collins, where Tracy had the same strains under test. The strains that were outstanding in leaf-spot resistance at Rocky Ford were also outstanding at Fort Collins.

It was clear, therefore, that to breed leaf-spot-resistant varieties selection and continuous inbreeding would be required until the factors for resistance were stabilized. Such work was begun by Coons and his colleagues using the Tracy strains and other selections as the basis. It was soon found that, whereas inbreeding stabilized the characters governing resistance, there was definite tendency for the strains to lose vigor. It was therefore very heartening in 1932, and later, to find that hybrids between two relatively nonvigorous types showed strong heterosis response. Inbreeding technique could thus be utilized to increase and stabilize leaf-spot resistance. The job of breeding for leaf-spot resistance resolved itself into production of as many distinctive leaf-spot-resistant inbreds as possible, and then making hybrids among them to find the pairs that would give greatest heterosis response.

The first leaf-spot-resistant variety introduced in 1937 (U.S. 217) was a synthetic made from 5 inbreds, all with better-than-average leaf-spot resistance. Seed stocks of the 5 were pooled, and plants were grown in the seed field from the seed mixture so that all types could intercross. The variety proved to be very resistant to leaf spot, high in sucrose, but somewhat low in root yield. It was soon replaced by U.S. 200 × 215. This variety was obtained by pooling the seed of Inbred U.S. 200 and Inbred U.S. 215 and planting the mixture in the seed field, thereby allowing the two components to flower together and intercross. Since the sugar beet has perfect flowers, and among inbreds there is more or less tendency toward self-pollination, a variety produced from a planting stock made by pooling of seed consists not only of the hybrid but of sibs of parent varieties as well. The proportions of these classes cannot be predicted and may vary from field to field. It was hoped that in U.S. 200 × 215 about 40 percent of the progeny would be hybrid. Heterosis shown by a hybrid portion is more or less nullified by the lower yields of inbreds in a progeny. One of the inbreds, how-

ever—U.S. 215—was noteworthy among all available strains, because it was highly productive, about equaling European commercial varieties in root size. Its sibs probably did not bring about depression of yields.

U.S. 200 × 215 was ready for introduction in 1939 when the European war cut off supplies of foreign-grown sugar-beet seed and forced the American industry to move 100 percent into domestic seed production. Seed supplies of the inbreds, U.S. 200 and U.S. 215, were available from Federal sources to furnish the planting stock from which commercial seed for the affected districts of the humid area could be produced, thereby averting a seed crisis such as that of 1914–18. It is noteworthy that the variety supplied was not a mere stopgap but an improved, disease-resistant variety at least 5 percent more productive than the European varieties it replaced.

By continued breeding research, new leaf-spot-resistant varieties have been introduced, notably U.S. 215 × 216, which, in its current phase, will be almost exclusively grown in many districts subject to leaf spot. This variety without leaf spot is equivalent in sugar production to the European varieties previously grown. Under conditions of leaf-spot exposure, it is greatly superior, exceeding the susceptible European types by 10–15 percent or more, depending on the severity of leaf-spot attack.

NEW PROBLEMS FOR THE PLANT BREEDER

It is a common experience among plant breeders that when certain primary requirements in plant improvement are met then other plant characteristics are revealed as of great importance. Thus, when growers attempted to utilize the new curly-top-resistant sugar-beet varieties in winter plantings in central California and in the Imperial Valley, these varieties showed such strong tendency to bolt—that is, to go to seed in the first, or vegetative, year's growth—that fields became a tangled mass of seedstalks. These had to be cut and disposed of before the roots could be harvested. One field was reported as yielding 16 tons of roots and 9 tons of tops. To meet this the plant breeders came forward with U.S. 15, a sugar-beet variety that, although only moderate in curly-top resistance, has strong resistance to bolting. The variety is also resistant to downy mildew and to rust, two other diseases serious in California coastal districts; hence, it is very well adapted to California conditions.

This variety was the product of breeding research conducted at the New Mexico Agricultural Experiment Station by Coons, Stewart, and Elcock and was obtained by selection from a high-sugar European variety. The variety was about to be dropped because of its extreme susceptibility to leaf spot when its tendency toward low bolting was discovered in tests conducted near Davis, California. Introduced into commercial use in 1938, the variety has become the stand-by for all winter plantings of sugar beet.

The most noteworthy achievement of U.S. 15 is the bringing about of successful sugar-beet culture in the Imperial Valley of California, a matter signalized by the opening in 1948 of the new $5,000,000-factory near Brawley, California. In its sugar-beet production, the vast, fertile Imperial Valley, watered by impounded waters from the Colorado, takes advantage of climate by reversing the order of plant growing seasons. Seed of U.S. 15 is planted in October, the plants of this cold-tolerant variety grow during winter, and the roots are ready for harvest in May and June. With such a planting schedule, and with the onset of cold weather soon after planting, ordinary varieties of sugar beet would bolt so much as to be almost unusable. There is sometimes a light exposure to curly top; hence, the combination of resistance to both bolting and curly top makes this variety of especial value. Over a number of years the Valley has given average yields of better than 18 tons per acre, with average sucrose percentages of not less than 18 percent. Such a record indicates that the area is one of the great sugar-producing regions of the world.

Another serious disease problem has been brought to the sugar-beet breeder. In the humid area, stands of sugar beets are often decimated by a seedling and root disease called black root. Research has determined that the primary cause of black root is a phycomycete, *Aphanomyces cochlioides*. Other damping-off organisms associated with seedling diseases are either less important or more readily controlled. The sugar beet will not attain a position of stabilized production in the United States, nor will full mechanization be possible, until a control is found for this disease, which strikes at the stand of plants in the field. Here again breeding of resistant plants represents the solution. Since the area is also subject to leaf spot, control of black root requires superimposing of resistance to the black-root fungus upon resistance to leaf spot. Fortunately, U.S. 216, the most leaf-spot-resistant inbred available, is outstanding in its resistance to black root, so that a start toward the desired combination has been made. Active breeding research has been under way three years, and

Comparison of leaf-spot-resistant variety (A) with nonresistant variety (B). *Cercospora* leaf-spot blights leaves of susceptible plants.

promising results have already been achieved by mass selections within the leaf-spot-resistant sorts.

NEW TECHNIQUES IN SUGAR-BEET BREEDING

Other developments in sugar-beet genetics may have important applications in meeting the situations that confront the domestic sugar industry. Tetraploid sugar beets have been produced by use of colchicine and other chemicals, and these may eventually be found to contribute something of value. So far as the research has gone it is evident that tetraploidy of itself does not automatically confer increased sugar production. The tests indicate that tetraploidy leads to increased vegetative growth, thereby giving greater root size, but the tendency to remain in growing condition results in a lower sucrose percentage. Thus the increased root size is compensated by the lower sucrose percentage, and sugar yield is not enhanced. An interesting feature of the tetraploids is the tendency of the seed balls to be one- or two-germ, indicating that by tetraploidy a seed ball could be obtained that would give one, or at most two, plants in a place instead of the plant clumps such as arise from an ordinary seed ball. Triploids have been produced and are under test to determine performance. It is significant that curly-top or leaf-spot resistance shown by a parent diploid variety continues in the respective polyploid form at about the same level.

One of the greatest advances in breeding techniques has come from the discoveries of F. V.

Owen on male sterility in sugar beets. His work has shown that one form of male sterility in sugar beets is cytoplasmically inherited. Flowers borne on plants whose cytoplasm is of the S type, if fertilized by pollen from plants bearing the proper complementary Mendelian characters, give rise to a progeny that is 100 percent male sterile. The situation with sugar beets is akin to that reported for the onion by Jones and his associates and for some other plants. The discovery is especially significant because it opens the way to production of seed that is 100 percent hybrid, a thing previously not possible.

Practical application of the male sterile character in sugar-beet breeding may be illustrated by work now in progress in production of a leaf-spot-resistant single-cross U.S. 216 × 225. As indicated, it is necessary to discover resistant lines and stabilize them by breeding. To restore vigor and take advantage of heterosis, single-cross hybrids or synthetic varieties are produced from the appropriate inbreds. The percentage of hybridization obtainable in the seed field is a matter of chance so long as the only practical method of obtaining some intercrossing is the pooling of seed stocks used to plant the seed field.

Tests have indicated that the hybrid between Inbred U.S. 216 and Inbred U.S. 225 is leaf-spot-resistant, high-yielding, and high in quality. By repeated backcrossings the male sterile character, originally from Dr. Owen's material, has been incorporated and a male sterile equivalent of U.S. 216 produced. If the pollen in future backcrossings is from hermaphroditic U.S. 216 plants chosen for the proper Mendelian characters, then the plants produced from seed grown on U.S. 216 male sterile plants should be 100 percent male sterile. Once the hermaphrodite is purified so that it carries only the proper complementary factors, it is possible to continue the male sterile phase of U.S. 216 indefinitely. U.S. 216 MS is being grown in Oregon seed fields bordered by rows of U.S. 225 to serve as pollinizer to produce U.S. 216 × 225. The stock of U.S. 216 does not as yet show complete male sterility, but it is expected to produce about 75 percent male sterile plants, the remainder being relatively weak pollen producers. In the seed produced, the percentage of sibs should not be important. In future productions of hybrid seed it may be possible, through manipulation of the genetic material, to obtain seed that is 100 percent hybrid.

The new discoveries give promise of permitting the sugar-beet breeder to obtain with his material what the corn breeder accomplishes by his detasseling technique. It will be remembered that in the production of hybrid corn all pollen-producing tassels of inbred "A" are removed in order that the ears on the detasseled plants may be pollinated solely by inbred "B" grown in adjacent rows.

Applications of the male sterility technique in the production of hybrids have gone forward so rapidly that is has not been possible to appraise fully what may be expected. There are results from Dr. Owen's laboratory with curly-top-resistant varieties that indicate that hybrids of curly-top-resistant lines made by utilization of male sterility reach a new plateau of sugar-beet productivity. With the leaf-spot-resistant varieties, advantages have come from the earlier introductions of U.S. 200 × 215, U.S. 215 × 216, and U.S. 216 × 225, in spite of the

Hybrid vigor test, Arlington, Va. Representative roots of the hybrid, U. S. 215 × 216, are shown at center, with a similar number of roots of the mother and pollen parents at right and left.

Variety test at State College, N. M., under conditions of severe curly-top exposure. U. S. 15, leading variety for fall plantings in the Imperial Valley and for winter plantings in Southern California originated from the plants growing in Row 277 A. (Photo by H. A. Elcock, October 2, 1930.)

fact that intercrossing was a matter of chance and hybridity of the seed was only partial. These give abundant promise that if the seed is 100 percent hybrid there will be superior performance. There is reason to expect, also, that disease resistance can be enhanced, since eventually all plants in the field will be the progeny of mother plants high in leaf-spot resistance.

Taking stock of our progress, research is well on the way toward gaining and holding for the sugar-beet industry a considerable degree of control of the major diseases, curly top, leaf spot, and soon of black root. In addition, the heritable characteristics that control bolting, downy-mildew resistance, and rust resistance have been combined with moderate curly-top resistance. In varieties about to be introduced these factors have been combined with high curly-top resistance and other desirable characters. The research program must take cognizance of the fact that viruses and fungus diseases are not static entities, but are constantly changing. It is almost axiomatic in plant pathology that the strains and biological forms that cause serious outbreaks of disease so change over a number of years that the resistant varieties once capable of meeting a situation became ineffective and must be replaced. The program for control that is based on resistant varieties must be a continuous one if new virulent forms of virus or fungus are not to nullify the gains that have been made.

The work I have outlined has stressed the research of the Department of Agriculture with which I am familiar. Plant breeders of beet-sugar companies and of the State Experiment Stations by their research, in part utilizing strains from the government program, have made and are making important contributions to varietal improvement. They have produced varieties that in addition to affording disease control open the way to greater productivity. Now that disease problems are more nearly met, there are opportunities for plant breeders to attain even greater local adaptation of varieties, to utilize polyploidy, and especially to capitalize on vigor of hybridity.

These normal developments of the breeding program are being elbowed to one side by new requirements forced to attention by the economic situation confronting the sugar-beet industry. A surplus of sugar on the world market may further depress the already low prices of sugar. In such an eventu-

ality, only those segments of the industry capable of producing sugar with the greatest degree of efficiency can hope to survive.

It is generally recognized that the greatest costs in production of beet sugar, and those offering the greatest chance of economies, are farm costs in producing the sugar beet. The price paid for the roots to be processed amounts to nearly half the cost of the sugar produced. Reduction of costs on the farm must come from greater production per unit of area worked and from reduction of the large amount of hand labor now used in growing the crop.

The breeding programs already under way are making every effort to increase production. If combined with improved agricultural practices they will do much to raise farm productivity. The greatest demand is further to reduce labor costs. In the operations described earlier, hand labor has been employed to block and thin the crop and to hand hoe it two or more times. What the industry must have if it is to reduce costs of sugar-beet production in the first half of the season is a full mechanization of these operations. The fact that the sugar-beet "seed" is really a seed cluster means that seedlings emerge as clumps. An attempt has been made to counteract this by milling the seed to one- or two-germ units, but this has its disadvantages. So long as the seed unit as planted cannot be depended upon to give a single plant exactly where it is dropped in the drill row, then precision planting comparable to that attained with other crops is not possible. If the morphological character for single germness of seed could be introduced into the sugar beet, and if this character were combined with other essential characters such as disease resistance, high yield, and high quality, then the first step in full mechanization could be taken. A sugar beet whose seed has the character of single germness may be precision planted. If resistant to black root, stand would be maintained, and the rows could be thinned mechanically to an exact pattern. In many districts mechanized weed control would be entirely applicable. Thus the employment of hand labor to start the crop would be done away with.

Already the sugar beet is being harvested with considerable success by machines. Nearly 75 percent of the California crop and 50 percent of the Colorado crop in 1948 were machine harvested. Machines top, lift, and frequently elevate the roots to the truck, the beet tops being windrowed at one side. Sometimes the harvesting job is done as two operations and sometimes by a combine. One type of machine loosens and lifts the root by plowshares, then clasps the leaves and elevates the entire plant to the topping mechanism. Leaf-spot-resistant varieties that retain the beet tops in spite of blight conditions that otherwise would destroy them, have made possible the successful operation of machines of this type. This is a contribution plant breeding has made to mechanical harvesting of sugar beets.

Other contributions are on the way. One plant

The new hybrid variety developed by G. W. Deming at Fort Collins, Colo., from cross of globose red garden beet and the sugar beet, is streamlined for easier mechanical harvesting. (Photo by P. B. Smith, Beet Sugar Development Foundation.)

breeder has made definite advance in combining the globe shape of the red garden beet with desirable characters of root size and quality to produce an easy-lifting beet. In actual trials these beets, prevailingly peg-top in shape, lifted more easily and with minimum breakage—a desirable contribution to both efficient and economical handling.

At present the work of harvesting machines, coming at a time of labor scarcity, is not viewed too critically so long as the beets come out of the ground quickly and with not too serious loss from skips, breakage, or tare. It is to be expected that better and better performances will be demanded of harvesters, especially with respect to topping. If breeding research achieves greater uniformity of tops and crowns, then this may simplify the problem of the agricultural engineer. If breeding research improves keeping quality of roots in factory storage piles, then the present heavy losses from deterioration can be reduced.

THE FUTURE OF THE SUGAR BEET

Thus we have in the sugar beet a creation of science that has given great benefits to America. A vegetable mediocre in productivity has been transformed into one of the greatest producers of foodstuffs of all our agricultural crops. In Europe, its culture broke up a cropping sequence that was retrograde in its effects on the soil. It became the keystone of European agriculture. In America the sugar beet has functioned similarly. Allied to the dairy industry, it has built an agriculture that has maintained soil fertility and made farming in many districts profitable. It is the keystone of irrigation agriculture.

To achieve these results in Europe it was necessary to breed a highly productive sugar beet. For the crop to succeed in the United States it has been necessary to breed strains of sugar beet to meet disease hazards unknown to Europe.

The sugar-beet industry is now established in 22 states. A capital of nearly $250,000,000 is invested in factories and facilities for processing the sugar-beet crop. In their farm lands, improvements, and equipment, and their irrigation systems, farmers have an investment equaling that of the factories. Much of this development is in the West. The significance of the sugar beet to Western agriculture cannot very well be overemphasized. It is a cash crop that the farmer grows for an assured price. Its resistance to hail damage and to hazards of weather make for a dependable harvest. Most important, the sugar-beet crop is marketed in chemically pure form, and its by-products are fed to livestock and are marketed as meat. High freight costs preclude the growing of bulky, low-value crops on farms of the West located far from markets. For these farms, the sugar beet is almost an irreplaceable crop.

The sugar-beet industry is now faced with economic problems that threaten its survival. The contributions science has made give promise that research again can meet the challenge. If productivity can be increased, if disease ravages can be lessened, then the crop has a chance. If the machine can be made not only to turn the soil and to plant the crop but also to do the job of weed control and to harvest the crop, then the sugar beet can continue its benefaction to American agriculture. The plant breeder is asked to play a significant part.

REFERENCES

ACHARD, F. C. Anleitung zum Anbau der zur Zuckerfabrication anwendbaren Runkelrüben und zur vortheilhaften Gewinnung des Zuckers aus denselben. 1803. (Reprinted in Ostwald's *Klassiker der exakten Wissenschaften No. 159*. Leipzig: 1907, 72 pp.)

BRANDES, E. W., and COONS, G. H. Climatic Relations of Sugarcane and Sugar Beet. *U. S. Dept. of Agr. Yearbook 1941*. 421–38.

CARSNER, E., *et al.* Curly-Top Resistance in Sugar Beets and Tests of the Resistant Variety U. S. No. 1. *U. S. Dept. Agr. Tech. Bul. 360*. 1933, 68 pp.

CARSNER, E. Development of Curly-Top-Resistant Sugar Beet Varieties. U. S. Dept. Agr. ARA, *Research Achievement Sheet 78 (P)*. July 9, 1947, 2 pp.

COONS, G. H. Improvement of the Sugar Beet. *U. S. Dept. of Agr. Yearbook 1936*. 625–56.

COONS, G. H. The Development of Domestic Sugar-Beet Seed Production. U. S. Dept. Agr., ARA, *Research Achievement Sheet 47 (P)*. Nov. 9, 1945, 2 pp.

LIPPMAN, E. O. VON. *Geschichte der Rübe (Beta) als Kulturpflanze*. Berlin: 1925, 184 pp.

MARGGRAF, A. S. Chymische Versuche, einen wahren Zucker aus verschiedenen Pflanzen, die in unseren Ländern wachsen, zu ziehen. In his *Chymischen Schriften*. Theil 2. Berlin. (Reprinted in Ostwald's *Klassiker der exakten Wissenschaften No. 159*. Leipzig: 1907, 72 pp.)

OWEN, F. V. Cytoplasmically Inherited Male Sterility in Sugar Beets. *J. Agr. Res.* 1943, 71, 423–40.

STEWART, D., GASKILL, J. O., and COONS, G. H. Heterosis in Sugar Beet Single Crosses. *Proc. Amer. Soc. Sugar Beet Tech. 1946*. 1947, 210–22.

STEWART, D., LAVIS, C. A., and COONS, G. H. Hybrid Vigor in Sugar Beets. *J. Agr. Res.* 1940, 60, 715–38.

TAYLOR, F. G. *A Saga of Sugar*. Salt Lake City: Utah-Idaho Sugar Co., 1944, 234 pp.

THE GENETIC APPROACH TO HUMAN INDIVIDUALITY

LAURENCE H. SNYDER

Dean of the Graduate College, University of Oklahoma, Dr. Snyder (D.Sc., Harvard, 1926) is well known for his work in genetics. He has taught at Harvard, North Carolina State College, Ohio State, and at Duke, and has participated in research studies of the Carnegie Institution and the National Research Council. His article is based on the paper he presented in the AAAS Centennial symposium on "Human Individuality" on September 14, 1948, Washington, D. C.

NO TWO human individuals are exactly alike. Variability is as much of a characteristic of human beings today as it is of all other species, and has been of living things throughout evolutionary history. Although no two persons are exactly alike, all human beings possess certain traits in common, and show certain similarities. The similarities and differences observable and measurable among people are the results of the interaction of genetic and environmental influences. It is becoming apparent that only modern genetic methods can successfully distinguish between the relative contributions of these interacting influences in bringing about human traits, and that the proportionate extent of these contributions will differ from trait to trait.

Human beings are most similar in those characters they share with the greatest variety of other animals, and differ from each other more and more as they get farther from these basic deep-seated traits and into the more superficial characters. We are chordates and we all have at an early stage in development a chorda, dorsal to the alimentary tract. We must assume that this is a hereditary trait, but we cannot specify the genes that result in the presence of a chorda, since we have never been able successfully to cross a chordate with a nonchordate and thereby to analyze the genes involved.

The fundamental chordate pattern is a remarkably constant characteristic of human beings. This may be due to the fact that whatever genes are involved in the production of this pattern are exceedingly stable and develop in relatively constant environmental surroundings, or it may very well be that any mutation interfering with this fundamental pattern is lethal. Living organisms, as a result of long ages of mutation and selection, have become highly adapted and delicately adjusted mechanisms, and fortuitous mutations, except those involving superficial characters, are apt to be, to say the least, harmful. Your watch is also a delicately adjusted mechanism. A fortuitous mutation might be likened to the result of jabbing an ice pick into a watch. If you jabbed enough ice picks into enough watches, you might come up with a revolutionary improvement in watchmaking, but the usual result would be to interfere with the normal working, or to stop the watch altogether.

Similarly, we are vertebrates and possess an ossified skeleton, much of which was preformed in cartilage. Mutations that prevented the appearance or development of the skeleton would most likely be lethal, but minor viable variations can and do occur, and these variations interfere more or less with normal functioning. More than one hundred mutations involving the skeleton are known in man, variously affecting the vertebral column, sternum and ribs, the skull, the pelvic and pectoral girdles, the long bones, and the bones of the wrist, hand, ankle, and foot.

Our mammalian characters of hair, mammary glands, and control of body temperature are somewhat less constant. Various mutations result in complete absence of hair, in excessive growth of hair, in persistence of lanugo hair, in complete absence of sweat glands, and in variations in the number, position, and functioning of the mammary glands. Here a mutational change can often be compensated for by man's ingenuity in controlling his environment. Thus we provide ourselves with varying degrees of clothing, with various hormone preparations, and we successfully feed and rear infants in the absence of human milk.

As we consider those traits that distinguish man taxonomically, we find such characters as the upright position, binocular vision, the opposable thumb, the development of the speech areas and the neopallium, and the loss of the external tail and body hair. Although mankind as a whole could probably not have developed to its present position without these traits, individual human beings can exist, with the aid of fellow-men, without one or more of these characters. Hence we find in any

human population today considerable variability in these attributes.

Within the species *Homo sapiens* there are many variations known to have a genetic basis. Through geographic or social isolation, and the concomitant effects of inbreeding, genetic drift, and selection, a number of populations have become more or less differentiated one from the other in respect to one or several of the more readily recognizable of these variations, such as skin color, hair form, or stature. Such physically differentiable populations have been variously referred to as races, strains, peoples, or ethnic groups. It should be noted, however, that from a genetic standpoint, these groupings have little resemblance to the races or stocks of the laboratory geneticist. Through systematic and intense inbreeding, the usual laboratory race has been made very nearly homogeneous in respect to its entire genotype. Whatever homogeneous human races may once have existed have been largely obliterated as such by migration, with consequent interbreeding and genetic segregation.

Within any existing population of human beings there are genetic and environmental variations of so many and diverse sorts that each human individual is unique. These variations have been the subject of study by many groups of investigators: philosophers, physicians, anthropologists, psychologists, biochemists, and geneticists. With the development of modern scientific methods fruitful results are rapidly accumulating regarding human individuality.

The twentieth century has witnessed the remarkable development of the understanding of the principles of heredity. This development includes not only the classical principles of the transmission of chromosomes and genes, but their physiological and biochemical activities, their evolutionary history, their distribution and behavior in populations, and the social, medical, and legal implications of many of the traits resulting from them. The understanding of these principles has given us the first clear insight into human individuality.

Based on the studies of salivary-gland chromosomes in *Drosophila,* a reasonable estimate of the minimum number of pairs of genes on a pair of chromosomes would be 500. With 24 pairs of chromosomes, we could reasonably assume a minimum of 12,000 pairs of genes in man. Given a mutation at each of only 200 of these loci, the number of possible phenotypically different combinations would be 2^{200}, or approximately 1 followed by 60 zeros, even if dominance were complete in all instances. If dominance should not be complete, so that the heterozygote were phenotypically recognizable, or if more than one mutation has occurred at a locus, resulting in multiple alleles, the number of distinct phenotypes that could result from combinations of genes at 200 loci might well exceed the staggering total of 3^{200}, or approximately 1 followed by 143 zeros. Either of these numbers far exceeds the number of human individuals who have ever lived on the earth. Evidence is accumulating that many human genes long supposed to show dominance are actually recognizable in the heterozygous state.

Mutations are now known in man at far more than 200 loci. True, the mutant gene of the pair is often rare in comparison with the original gene, so that certain combinations of mutant genes will be exceedingly rare, but through the workings of Mendelian heredity all the various combinations are potentially possible, and many of them will occur with reasonable frequency.

I

Let us examine some of the better-known mutations and assay their contributions in producing human individuality. One of the first pieces of research undertaken in my laboratory more than twenty-five years ago was the analysis of the inheritance and distribution in populations of the blood groups. At that time we knew only four blood groups, and we were able to confirm the hypothesis that their inheritance was on the basis of a set of three multiple alleles. Today, because of the researches of workers in many laboratories all over the world, we know more than two million blood groups, dependent upon ten or more sets of alleles. The inheritance of the groups is rather well known. The blood groups have been described in detail on many other occasions, and I shall do no more than list them here (Table 1).

TABLE 1

THE KNOWN HUMAN BLOOD GROUPS

Blood Group Systems	Number of Phenotypes
O, A^1, A^2, A^3, B, A^1B, A^2B, A^3B	8
Secretor, non-secretor	2
M, MS, N^1, N^2, N^1S, N^2S, MN^1, MN^2, MN^1S, MN^2S	10
P^1, P^2, P^1P^2, P–	4
C, C^u, C^w, c^v, c, CC^u, CC^w, Cc^v, Cc, C^uC^w, C^uc^v, C^uc, C^wc^v, C^wc, c^vc	15
D, D^u, d, DD^u, Dd, D^ud	6
E, Ee, e	3
Kell +, Kell –	2
Lewis +, Lewis –	2
Lutheran +, Lutheran –	2
Levay +, Levay –	2

$8 \times 2 \times 10 \times 4 \times 15 \times 6 \times 3 \times 2 \times 2 \times 2 \times 2 = 2{,}764{,}800$

Some of the groups are common in the populations, others rare. Moreover, the proportions of the various groups differ from population to population. The antiserums for determining the groups are not all equally readily available, and probably no one laboratory has ever had all the antiserums available at any one time. Nevertheless, it would be possible for me to take a drop of blood from each of hundreds of individuals and, with the proper antiserums, to classify each person in one or another of these many blood groups. It would be surprising if any two of them fell into the same groups. Then, ten years from now we could all meet, say, in a reunion, and I could again take a drop of blood from each person. Without labeling the samples at all, and merely by referring to my previous list, I could identify the blood of each person, except for such duplications of type as might occur.

Another source of human individuality lies in the enzymes and enzyme systems that characterize us. Modern biochemical research indicates that metabolism proceeds by a series of chemical steps, each activated by a specific enzyme. All these enzymes are, as a rule, produced by each individual. Now and then an individual is found who fails to produce a particular enzyme, and as a result some metabolic process is interfered with at that point. The outcome may be the excretion of some unusual metabolite in the urine, or it may be evidenced by lack of pigmentation in the hair or skin, or by physical or mental peculiarity. In such instances the failure to produce the enzyme has been shown to be the result of a single gene substitution. Ancillary investigations on *Neurospora* are providing evidence of a one-to-one correspondence between gene and enzyme; and, in fact, this one-to-one correspondence may very well apply equally to gene and antigen and to gene and hormone.

II

Let us consider four human traits that at first glance seem to have no close connections with one another, but which turn out to be very closely related chemically. The four traits are albinism, in which there is an absence of pigment in skin and hair; phenylketonuria, in which there is severe mental defect accompanied by the daily excretion of about a gram of phenylpyruvic acid in the urine; tyrosinosis, in which tyrosine is excreted in the urine; and alcaptonuria, in which the urine turns black on exposure, because of the excretion of homogentisic acid, and pigment deposits are sometimes made in the cartilages and joints.

Each of these conditions appears to be due to a separate recessive gene. A long series of biochemical investigations shows that they are all intimately related to the metabolism of phenylalanine. Each recessive gene results in the failure to produce a specific enzyme which is produced by its normal allele, and when the mutant gene is present in homozygous form the metabolic process is stopped at that point, often with the excretion of the blocked product into the urine (Table 2). In the table, *c* represents the recessive gene for albinism, which, when present in double dose, fails to produce the enzyme formed by its normal allele and necessary to build melanin from its precursor, "dopa;" *k* represents the mutant gene for phenylketonuria, which, in homozygous form, fails to produce the enzyme formed by its normal allele and necessary for the degradation of phenylpyruvic acid; similarly, *t* represents the gene for tyrosinosis, and *a* the gene for alcaptonuria.

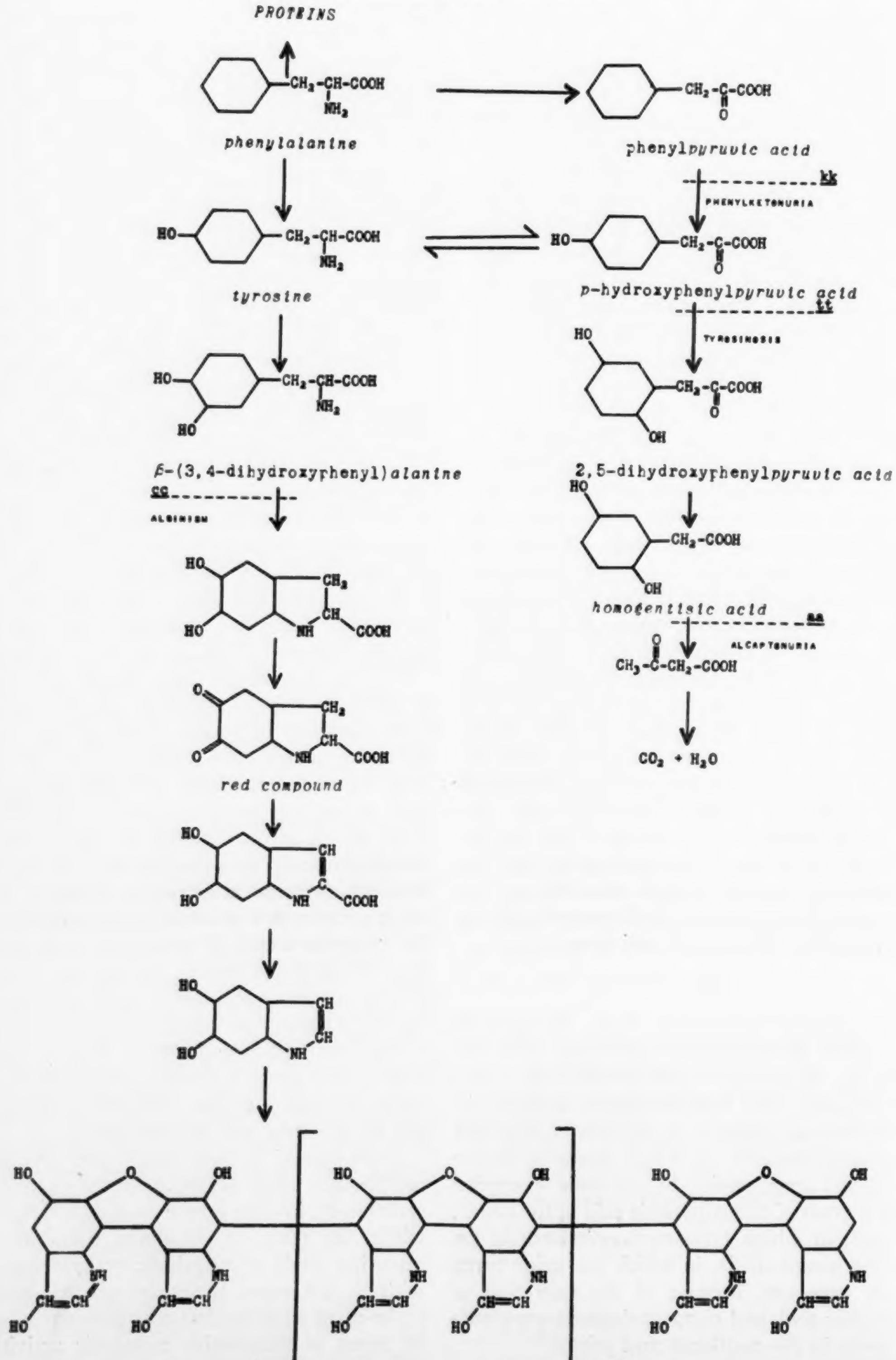
Thus these four metabolic derangements are seen to be chemically related and intimately bound up with the metabolic processes of the body. In a similar way glycogen disease, also due to a recessive gene, appears to be brought about as a result of the failure of this gene to produce the normal enzyme phosphorylase necessary to degrade glycogen into glucose-1-phosphate and so to glucose.

Human individuals show many other genetic variations in normal metabolic processes, many of them resulting in severe diseases. The detailed chemistry has not been worked out for all of them. Such inherited metabolic derangements as amaurotic idiocy, gargoylism, Gaucher's anemia, Niemann Pick's disease, xanthoma tuberosum, gout, and diabetes offer great possibilities for discovering the detailed chemical activities of genes. It is not too much to hope that someday the genetic basis for the complete metabolic processes of man may be built into a single mosaic. Indeed, the workers in at least one laboratory are already actively searching for variations in the normal metabolic activity of man, with gratifying results. Even at this early stage of the game it seems certain that each individual inherits a unique metabolic pattern, which can be measured and demonstrated.

Since several of these single-gene metabolic derangements, such as phenylketonuria and amaurotic idiocy, involve severe mental defects, it is well within the range of possibility that, through the intensive study of metabolic processes associated with mutant genes, the entire nervous and mental make-up of an individual may someday be specified in terms of measurable metabolic activities. Recent work with the electroencephalograph in meas-

TABLE 2

METABOLISM OF PHENYLALANINE



uring cerebral dysrhythmia indicates that this dysfunction is associated with the tendency to convulsive disease and is apparently inherited as a dominant factor. It remains for the detailed metabolism to be worked out.

The recognition of the genetic basis for many of the mental derangements has had to await the development of specific genetic methods. Indeed, the whole modern study of human individuality has required the elaboration of new and special methods. In so far as the analysis concerns genetic variability, the new methods center around two major approaches: gene-frequency analyses and twin methods. The gene-frequency procedures, which I have had occasion to formulate and elaborate on many other occasions, are used in the analysis of those traits in which genetic diversity provides the effective variable, and environmental diversity produces relatively little effect. The twin methods, which are becoming more and more essential in studies of human individuality, are used primarily in the investigation of those traits in the production of which there is reason to suppose that environment acts as an effective variable.

It has long been realized that there are two types of human twins: monozygotic, arising from a single fertilized ovum, which early in development has split into two parts; and dizygotic, resulting from two separate ova, which have matured and have been fertilized at the same time. The members of a pair of monozygotic twins are always of the same sex, and carry identical complements of genes. Differences between them must be attributed to environmental influences, including prenatal. Dizygotic twins, on the other hand, may be like-sexed or opposite-sexed, and the gene complements of the members of a pair will be in general of the same degree of similarity as those of ordinary brothers and sisters.

Many investigators have used the comparison of the two types of twins as a method of evaluating the relative contributions of heredity and environment in the production of various human traits, both normal and pathological. Recent refinements of the procedures, notably the twin-family method, have provided important evidence for the genetic basis of specific disease entities, physical and mental, as well as of basically uniform patterns in the organization or disorganization of physical and mental capacities essential in effort tolerance, personality integration, and intellectual performance. The twin-family method involves an extension of the comparison of twins to include not only monozygotic and dizygotic pairs, but also their full-siblings, half-siblings, step-siblings, and marriage partners. Long-term, extensive studies of this sort may be expected to provide information of the most important kind on human individuality. The interaction of genetic and environmental factors has already been thoroughly studied by this method in relation to schizophrenia, tuberculosis, and significant variations in intelligence, aging, and longevity, and there can be little doubt of the important part played by variable genetic factors in the development of these phenomena. It has also been indicated by experimental studies of animal behavior that the genetic determination of behavior may extend to very intricate and precise coordinative processes.

Human beings differ in their taste responses to various substances. These responses show a clear dichotomy in some instances, such as the ability or lack of ability to taste phenyl-thio-carbamide or mercapto-benzo-selenozol, and the responses are inherited in a simple manner. In other instances, such as the threshold responses to various substances such as NaCl and HCl, there is continuous gradation and high variability.

A long series of inherited variations in the blood is known, including differences in the serum, and in the shape, size, structure, and function of the various kinds of blood cells. Many of these variations result in clinical manifestations of greater or less severity.

In fact, no system of the body is without its genetic differences. The precise genetic nature of some of them is known, but for others the individual genes concerned remain to be specified. More than 100 mutations are known affecting the development and functioning of the eye, and many genes have been described having effects on the muscles, the nerves, the glands, the skin, the hair, the teeth, and the nails.

III

Man is a gregarious animal and tends to cluster in groups. The analysis of human genetic individuality is essentially a study of population genetics. Although the geneticist does not like the term race, with its implication of essential intraracial similarity and interracial difference, of "superiority" of one race and "inferiority" of another, nevertheless he realizes that human individuals do occur in populations, which may differ one from the other. Within any population there is considerable variability, giving each human being his own individuality. This individuality must be described in terms of the presence or absence of various alleles,

plus the appropriate results of the exigencies of the environment to which the individual has been exposed. In addition to the description of the individual human being, however, the geneticist must describe *populations*. These are best characterized in terms of the relative proportions of the alleles, and of the results of the over-all environmental impacts.

Human populations differ genetically one from the other almost entirely in the varying *proportions* of the alleles of the various sets, and not in the *kinds* of alleles they contain. In all the instances extensively studied, it appears likely that no large population completely lacks any allele, but that one population may have a larger or smaller proportion of a given allele than another.

By special genetic methods it is possible to derive from the proportions of the various phenotypes in any population the relative proportions of the alleles producing these phenotypes. The genetic description of a population would then be the detailed listing of these proportions for the various alleles of all sets that have been identified and analyzed for the population. This type of description is as yet in its infancy for the human race, but its accomplishment is an urgent necessity for the understanding of human individuality. It is gratifying to note that this viewpoint is being adopted by physical anthropologists.

Since the genetic individuality of any human being is a function of the family and of the population to which he belongs, the principles of both Mendelian genetics and population genetics must be taken into account in its analysis. The principles of Mendelian genetics are now household commonplaces, but the principles of population genetics are not so widely understood. I have recently had occasion to organize these principles, and they might well be summarized at this point.

1. In a large population, with negligible or balancing effects of mutation, selection, and genetic drift, the proportions of the alleles of any set will remain constant from generation to generation. Under a system of random mating, the proportions of the genotypes formed by these alleles will likewise remain constant in the equilibrium ratio.

2. Under certain specifiable conditions, mutation and selection can change the proportions of the alleles in a predictable manner.

3. Classical Mendelian ratios are not necessarily to be expected among the pooled offspring of a series of families where the parental mating types are phenotypically identical.

4. Although classical Mendelian ratios are not to be expected in combined family data, nevertheless predictable ratios do occur. These ratios are population ratios, and are expressed in terms of gene proportions. Thus, where a common Mendelian ratio is $\frac{3}{4} : \frac{1}{4}$, an equally common and analogous population ratio is $\frac{1+2q}{(1+q)^2} : \frac{q^2}{(1+q)^2}$, where q represents the proportion of the recessive allele in the population.

5. The analysis of population ratios may serve as a means of estimating the number and kinds of genes in a population, just as the analysis of Mendelian ratios may serve as a means of estimating the number and kinds of genes involved in a laboratory experiment.

In closing let me attempt to illustrate by concrete examples an arrangement of human variations in an order of increasing importance of heredity as an effective variable.

At one extreme of such an arrangement we might place such a trait as the language spoken by an individual. The particular language used, and the accent with which it is spoken, are probably almost entirely due to the environment in which the individual is brought up, and are little if at all affected by his genetic make-up.

Going one step further, I will call to your attention a case recently given me by a physician who had been a student in one of my classes in medical genetics. A man of fifty-one years was admitted to a hospital with symptoms of extreme breathlessness. It was noted that he had clubbed fingers, and this combination of symptoms caused the probability of severe cardiac disease to leap to the minds of the examining physicians. After extensive studies no such pathology could be demonstrated, however. On at least three previous occasions the patient had been told by examining physicians that he had serious heart disease, and on two occasions he was refused lucrative employment following the diagnosis.

Recalling his training in medical genetics, the physician asked the patient if anyone else in his family had clubbed fingers. The patient replied that his father had them, as did two of his five children. The final and correct diagnosis of this case was that the patient had inherited clubbed fingers, and that after being told so often by doctors, on the basis of this trait, that he had serious heart disease, he had developed an almost incapacitating anxiety reaction.

This case is obviously one where the trait is en-

vironmentally conditioned, but results indirectly from the presence of a genetic factor.

Going another step, we may consider a trait that is also environmental, but which results directly from the presence of a genetic factor. I refer to erythroblastosis, or hemolytic disease of the newborn. Here the condition is brought about by a chain of reactions, involving the inheritance in the embryo of an antigen present in the father but lacking in the mother, followed by the immunization of the mother by the antigen of the embryo, and the subsequent effect on the erythrocytes of the fetus, or later similar fetuses, of the maternal immune antibody.

The lines upon the fingertips, which account for much of the popular conception of human individuality, are the result of the interaction of both genetic and environmental influences. The similarity of fingerprints increases as the closeness of blood relationship increases, but the fortuitous stretching of the skin during embryonic development prevents them from ever becoming identical in any two persons. Likewise, many pathological conditions such as diphtheria, tuberculosis, cancer, and schizophrenia, in which both a genetic susceptibility and an environmental impact or infectious agent are required for their manifestation, illustrate traits that are obviously the result of both hereditary and environmental variables. Finally, we may point to such traits as the blood groups or the color of the eyes, in which genetic diversity appears to be the only effective variable, and in the variation of which environmental diversity seems to play no role.

Many and diverse are the modes of interaction between hereditary and environmental influences. And many and diverse are the resulting measurable human traits. The manifold combinations of these traits result in the almost infinite diversity of human individuality, a diversity we are just beginning to comprehend.

MEDICAL RESEARCH

New Betatron

The University of Illinois has set up a 22,000,000-volt betatron for pioneer medical work. X-rays now used in hospitals for treating deep cancers are of 200,000–2,000,000 volts energy. The new betatron may later become standard for deep treatment.

Professor Donald W. Kerst, the betatron's inventor, "using material which absorbs rays equally with a living body, has found that 22-million volt X-rays have their greatest effect approximately 1.5 inches (3–4 cm) inside the surface, and that after passing through 8 inches (20 cm) of the material their energy is only about one-half that of the maximum point. The 8 inches corresponds to an approximate thickness of the human body.

"This means for medicine that surface damage, at points where the ray beam enters and leaves the patient, will be less, and at the same time that the X-ray dosage is concentrated in maximum on the deep internal organs where it is desired."

Dr. Roger A. Harvey, head of the Department of Radiology, is directing preliminary research involving studies on depth dose and isodose distributions, rate and intensity effects, directing, focusing, and monitoring of the beam, and techniques for biological and clinical application.

Radioisotopes

The Veterans Administration has authorized the establishment of a radioisotope unit at the VA Hospital, Nashville, Tennessee. Research work will be directed toward development of improved methods for clinical diagnosis and medical treatment of veteran-patients. Radioisotopes to be used in the preliminary work are radio phosphorus, radiosodium, radioiron, and radioiodine. This is the eleventh such unit established by the Veterans Administration.

DOVAP—A METHOD FOR SURVEYING HIGH-ALTITUDE TRAJECTORIES

DORRIT HOFFLEIT

Dr. Hoffleit (Ph.D., Radcliffe, 1938) worked at the Harvard College Observatory on variable stars, meteors, and especially spectroscopic absolute magnitudes from 1929 until the war called her to the Ballistic Research Laboratories, Aberdeen Proving Ground. She is still serving both institutions. Radcliffe awarded her its Caroline Wilby Prize in 1938 for the "best original work in any department."

AT THE White Sands Proving Ground in New Mexico many sorts of instrumentation are employed for determining the paths of V-2 and other high-altitude, long-range missiles. The instruments used include a variety of optical devices, such as cine-theodolites, tracking telescopes, and ballistic cameras. There are several varieties of theodolites. Some are fixed in orientation and situated only a mile or two from the launcher. On movie film they record the initial part of the flight of the missile with a high degree of positional accuracy. Askania and Mitchell theodolites, using 35-mm film, are tracked on the missile and follow it about 30 miles—sometimes much higher, depending on illumination and atmospheric transparency. Ballistic cameras are fixed cameras operating on the same principle as Harvard's meteor cameras, which give positions and velocities from trails segmented by rotating shutters. A pair of synchronized optical instruments is required for triangulating the position of the missile. Numerous stations are distributed over the range in order to give best results at all available missile positions. Then there are radar devices. One in particular gives the slant range of the missile from the instrument to a moderate accuracy of 50 yards, with corresponding azimuth and elevation angles accurate to a few mils (1 mil = 360°/6400). One station alone can therefore determine an entire trajectory, and radar has the advantage over the optical devices that it can *see* the missile regardless of illumination.

All these types of systems had been much used with shorter-range missiles when the V-2 tests at White Sands were begun. Each has its peculiar advantages and disadvantages. No one system has yet proved "best" for all the information that is wanted on a missile's entire flight path and behavior (including velocity, deceleration, spin, yaw, etc.). Another system, now known as DOVAP (meaning DOppler Velocity And Position), although previously existing on paper, was developed by Ballistic Research Laboratory engineers as a practical instrumentation especially for the V-2 tests and for the future, in a more mature form, for newer, longer-range missiles. This system is of timely interest. It has definitely proved its practical value, yet nearly every record obtained seems to have opened up new vistas for research or engineering improvement. Moreover, in the analysis of the data obtained, new film-measuring and computing devices have either been developed or tested for the first time.

DOVAP uses continuous-wave radio signals to determine missile distances by a Doppler effect. A transmitter on the ground sends these signals simultaneously to a ground receiver station and to the missile. On the nose of the missile is a transceiver which receives the transmitter signals, doubles their frequency, and retransmits the doubled frequency down to the ground receiver. In the ground receiver this signal from the moving missile is mixed with double the frequency received directly from the transmitter. The resulting beat frequencies are recorded as Doppler waves along a time scale. If we count the number of recorded cycles from the instant the missile has left the ground to any specific future moment, t, the number of counted cycles tells us how much the total distance Transmitter-Missile-Receiver (TMR) has changed in that period of time. Let N_1 be the number of counted cycles and λ the Doppler wave length. This is determined from measures of the transmitted frequencies, f-, since $\lambda = c/2f$, where c is the velocity of propagation of radio waves (the velocity of light). Knowing from ground surveys the distance from the transmitter to the launcher (TL), and from the launcher to the receiver (LR), the Doppler information tells us that the distance $\mu_1 = TMR_1 = TL + LR_1 + N_1\lambda$. What this means is that the missile is somewhere on an ellipsoid of revolution (strictly a prolate

spheroid) whose foci are the transmitter and the receiver. If we now install a second receiver somewhere well separated from the first one, we obtain precisely similar information, namely, $\mu_2 = TMR_2 = TL + LR_2 + N_2\ \lambda$. Hence we know that the missile is somewhere on an ellipse which is the intersection of two prolate spheroids having one focus, the transmitter, in common. Finally, if we introduce a third receiver, served by the same transmitter, we find two points which satisfy all three conditions μ_1, μ_2, μ_3. There will be no trouble deciding which solution is the desired one—the extra solution is usually underground.

In practice, four receiver stations are actually used at White Sands, arranged roughly at the corners of a diamond, the transmitter and one of the receivers being close together and about 2 miles south of the launcher (Fig. 1). The distances to the other stations are about 14 miles. Four stations are used partly as precaution in case any one of the stations should fail, partly to enable us to evaluate the accuracy of the results. The Doppler signals obtained at the four receiver stations are all transmitted by ground wire to a common recording station, where they are recorded simultaneously, side by side on 35-mm movie film, together with the timing record (Fig. 2). As the transmitted frequency (38.5 mc) corresponds to a Doppler wave length of about 12.5 feet, and the time scale is accurate to better than 1 part in 100,000, it would appear at first sight that the distances μ_i, determined from counts of cycles (such as illustrated), might be accurate to within a foot. Actually, most of the records suffer blemishes, due, for example, to peculiarities in missile behavior, interference of radio waves, and atmospheric effects. Usually errors in the μ_i amount to about 50 feet; at high altitudes the errors may be much larger if refraction in the ionosphere is disregarded. Yet at 100 miles overhead absolute errors of even a few hundred feet still surpass in accuracy results from any of the other present types of position determinations. An average error of 100 feet in Transmitter-Missile-Receiver distances will intro-

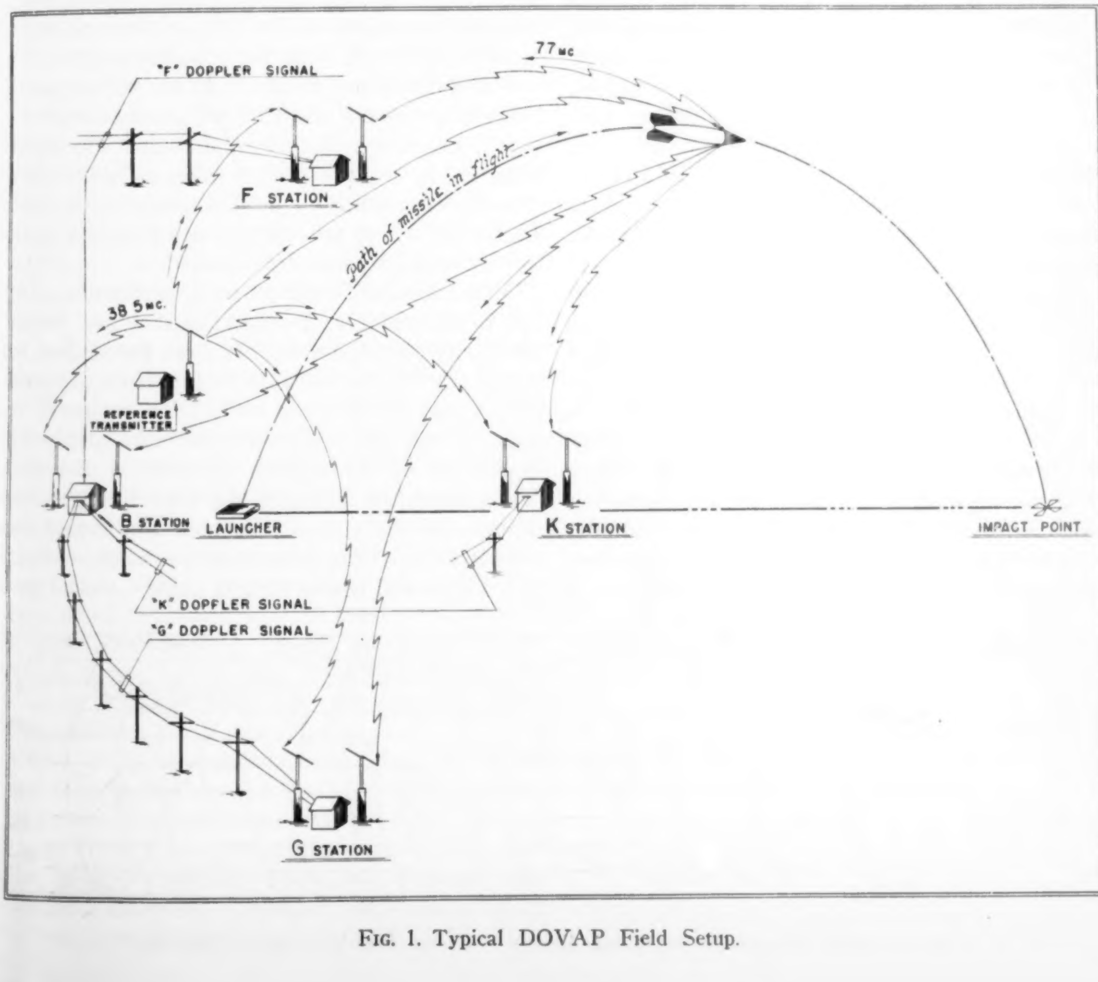


FIG. 1. Typical DOVAP Field Setup.

duce errors of under a mile in the horizontal component of the range and not over a few hundred feet in height. Moreover, improvements both in the instrumentation and data analysis are actively progressing.

The complete reductions of DOVAP data on any one round are apt to require a matter of several weeks of film reading, interpretation, and computation. There is, however, a quick method that has been used successfully for determining a few critical points on the trajectory within a few minutes after firing. The Doppler frequencies are recorded directly with an Esterline-Angus Recorder, giving a trace such as shown in Figure 3. The abscissa on this curve is time; the ordinate, frequency which is proportional to velocity. In the case of B-station receiver, which is close to the transmitter in comparison with the distances to the missile, we can assume that the recorded frequency is directly proportional to the radial velocity of the missile toward or away from the receiver. With the aid of the schematic diagrams in Figure 4 we can interpret the Esterline-Angus record. The upper diagram is a hypothetical V-2 trajectory. B-station and the transmitter are 2 miles behind the launcher at about the same height. The missile rises vertically so that initially (*A*) the radial component of its velocity as seen from B-station is zero. At fuel cutoff (*B*), at an altitude of about 20 miles, the missile has been guided so that its trajectory is nearly tangent from B-station. The radial velocity is consequently a maximum for two reasons: the missile's speed is a maximum, and the angle between the line of sight and the direction of motion is a minimum. Shortly after maximum altitude (*C*) the trajectory is perpendicular to the line of sight and the radial velocity is zero. On the continued downward path the radial velocity again increases (to *D*), but usually it does not reach as high a value as on the ascending branch because the line of sight is nowhere tangent to the path. A second null point (*E*) may, however, occur prior to impact (*F*). The lower diagram is

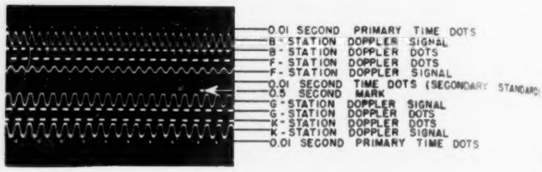


FIG. 2. Representative segment of DOVAP record.

thus a schematic Esterline-Angus record, which gives rate of change of distance.

If we take a planimeter and trace the area under the first hump of the record, from *A* through *C*, we have the complete change of distance from launching to the point slightly after maximum altitude. Since the V-2 trajectories are very steep, and B-station comparatively close to the launcher, it can be assumed within 5 percent that this net change of distance is the maximum altitude. The second hump of the tracing, from *C* to *E*, represents a *decrease* in the distance of the missile; the small final hump represents another increase. Thus, if we subtract the second area from the first and add the third, we have the difference in distance from launching to impact—the range.

From data from B-station alone we can in this manner get good estimates of the maximum velocity, maximum altitude, and range. The results obtained by the press right after a "shoot" have usually been obtained as described. With just a little more effort an approximate direction to the impact area may also be obtained.

The Esterline-Angus records for the other, outlying, stations give frequencies that are proportional not to radial velocities from the station, but to the sum of the radial velocities from the transmitter and the receiver station. To get radial velocities from the receiver we therefore simply subtract half the frequencies observed at B-station. Then we obtain as before the impact ranges from all four of the stations, defining the impact area by the intersections of four circles whose radii are the ranges and whose centers are the station posi-

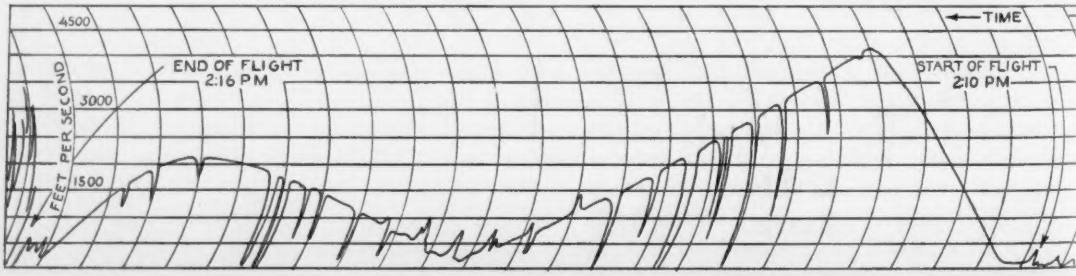


FIG. 3. Doppler frequencies registered directly with an Esterline-Angus Recorder.

tions. This area determined from three stations is about 2×4 miles.

These planimeter readings of Esterline-Angus records are gratifying for the speed with which they yield order-of-magnitude results. The detailed reductions of the DOVAP records themselves may be very time-consuming, even in comparison with the reductions of photographic measurements. If a missile's flight is successfully recorded from take-off through maximum altitude to warhead blowoff, or impact, we may have nearly a thousand feet of film to examine. If the maximum altitude reached was about 100 miles, approximately 40,000 cycles would have been recorded for the ascending branch of the trajectory for each of the four stations, and about the same number for the descending branch. Thus counts of more than 300,000 cycles would be made. Until recently all such counts were made purely by eye (with the aid of dividers). Counts were recorded for half-second intervals of flight time so that the smoothness of second differences might readily reveal mistakes. Even at such close intervals, up to 400 cycles per interval were counted at times near fuel cutoff. Photocell counters were tried but proved too inaccurate. Recently a mechanical counter operating on the stroboscopic principle has been developed and is proving successful.

After the Doppler cycles have been counted, the determination of missile coordinates requires some forty arithmetic operations for each point on the trajectory. A skilled computer using desk machines (Friden, Monroe, or Marchant) requires 15–45 minutes per point. A complete trajectory at half-second intervals would therefore require about 400 hours, or 10 weeks of working time.

The problem was first ready for numerical solution about the time that International Business Machines Corporation (IBM) had tested and delivered its new relay multipliers to Aberdeen. The estimated time for 800 points, including time of machine failure, was about 4 weeks on a 40-hour week basis. Now, two such machine units have been wired in tandem, and the problem is expected to take 5–8 minutes per point, or about 2 weeks. This estimate for the new procedure includes the time for complete checks on the accuracy of the computations.

The DOVAP problem was also among the first to be tackled by the ENIAC, which won great acclaim for its speed in the solution. The ENIAC requires about 2 days to get the machine set up for the specific problem. Thereafter (unless other problems intervene) it computes the coordinates in a time comparable to the time of flight of the missile itself: a 10-minute trajectory at half-second intervals in 10 minutes.

The Bell relay machines designed by Stibitz cannot boast this speed, but they do produce the results at a rate of 5 minutes per point without any significant preparatory set-up time. Moreover, they can run unattended all night. Thus their working day is 24 hours in comparison with 8 for the attendants. Hence, they could complete the 800-point trajectory in 3 days. If we have exactly one trajectory to reduce, these machines are proved highly efficient—comparable with the ENIAC. On the other hand, if we have data on 10 rounds at once the ENIAC would require the 2 days preparatory time plus only 100 minutes for all 10 trajectories, or a little more than 2 days.

Thus the DOVAP problem has automatically yielded practical intercomparisons on various high-speed computing devices demonstrating when a relatively slow but highly flexible machine is to be preferred over a higher-speed unit that requires much preparation. Our conclusions, however, reached a year ago, are already obsolescent; in the meanwhile, both the IBM relay multipliers and the ENIAC have undergone subsequent develop-

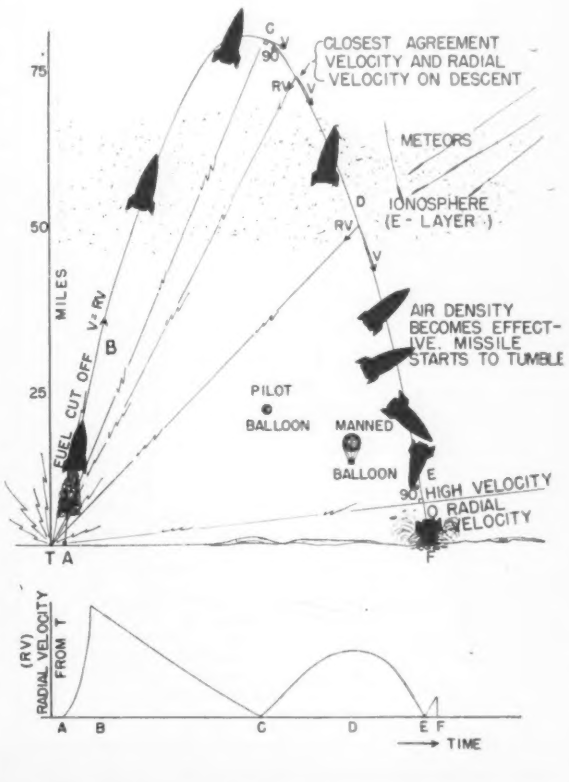


FIG. 4. Schematic diagrams interpret the Esterline-Angus record.

ment to reduce the "get-ready" time in the ENIAC and to increase the operating efficiency of the others.

Some of the DOVAP results are of interest. Figure 5 shows an array of trajectories determined prior to 1948. The round launched the night of December 17, 1946, reached the highest altitude, 116 miles, and had, throughout, the best Doppler recording on any round. For some rounds the records have faded out mysteriously at high altitudes, only to come in again, beautifully, after too long a gap for successful interpolation of counts across the gap. Could the ionosphere be responsible? All the other firings, except the round on December 17, were carried out in the daytime when ionization is stronger. We do not know the answer. One round seemed to defeat this attractive hypothesis by fading on the ascending branch of its flight path and reappearing shortly before maximum altitude (in the ionosphere) and returning good signals all the way on its downward path. Investigations are in progress to attempt to correlate high-altitude failures with solar activity.

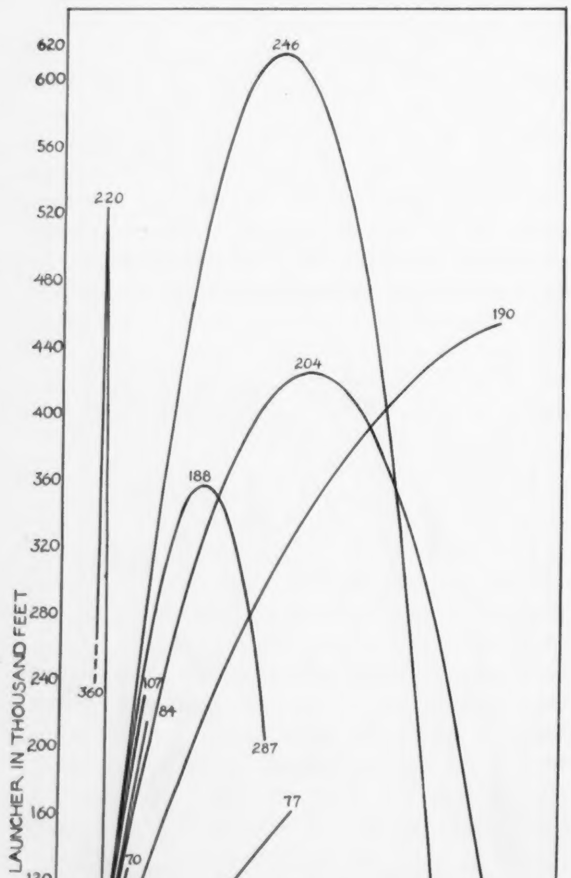


FIG. 5. Trajectories determined prior to 1948.

Sometimes short stretches of fading are found that could be due to the interference between radio waves reaching the missile directly and waves that were first reflected from the ground. But the terrain at White Sands is bumpy, with humps having dimensions comparable with the wave length. Absorption and scattering of the radiation are therefore more apt to be effective than the reflection of radio radiation.

Perhaps the most exhilarating observation was that a spinning missile gave Doppler records with periodic cancellations. Sometimes cycles could still be counted in the low-amplitude cancellation stretches, sometimes the signal loss was complete. Such breaks occurred usually twice per period of spin but sometimes four breaks per rotation occurred. On the basis of direct interpolated counts, it was found that the missile position for such rounds was very badly determined, as compared with optical or radar results. We must apply systematic corrections to the observed frequencies to get quantities that give change of distance directly when multiplied by the wave length. What the corrections should be was a problem in antenna design, supplemented with empirically ascertained correction factors. The missile roll-rate effect gave both pleasure and sorrow when it was first found. It meant we could learn other things from DOVAP about the missile, besides its flight path, velocities, and accelerations. On the other hand, it reduced what should otherwise have been very accurate counts to somewhat unsatisfactory problems in interpolation and interpretation. The engineers are working on the problem, however, to get legible records without cancellations or fade-outs; but the observed frequencies will still have to be corrected for roll rate. Provided the roll rate is not too fast it can still be determined throughout the time of flight from Esterline-Angus field-strength recordings and from tracking telescope records.

Various other types of apparent blemishes have also been observed on some of the records. Some may be due to spontaneous discharge of static picked up by the missile in flight. Some might have arisen from diffraction or reflection from the large,

smooth gypsum dunes at the White Sands National Monument, 25 miles north of the launcher. Here again, scattering and absorption may be the more important. Yet there are fairly regular configurations in the white sands that stimulate interest as possible sources for error in the interpretation of DOVAP records. Then there is the important problem of the effect of refraction of radio waves in the ionosphere. Neglect of this effect should make our high-altitude determina-

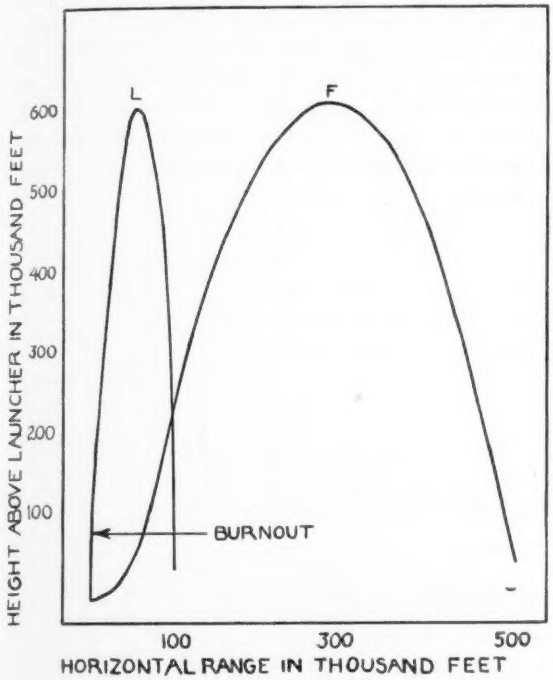


FIG. 6. Curve L is an A-4 trajectory as observed relative to the launcher. Curve F shows how the same trajectory would look to an observer in "fixed space." Above 30 miles this is practically an ellipse, whereas curve L is slightly steeper on the descending than on the ascending branch.

tions wrong by several hundred feet. DOVAP is still a young system and loaded with research promise.

The accuracy of DOVAP-determined trajectories nevertheless compares favorably with results from older instrumentation. Some rounds have given trouble; but with the source of major troubles discovered, higher accuracy in the future seems assured. And this is important, not for V-2s, but for the longer-range missiles or space ships of the future.

From the internal consistency of four DOVAP results obtained by using three at a time of the four field stations, the determinations of altitude have usually been found to agree to much better than 100 feet, and the horizontal components of the slant range have agreed to half a mile at the largest observed distances.

Perhaps a more striking evaluation of the accuracy is found in a comparison between DOVAP and theoretically computed trajectories. For these high-altitude missiles we might assume that atmospheric resistance is negligible above 25 or 30 miles. Then we can compute a "vacuum trajectory" to see how well it fits the DOVAP results. The vacuum trajectory is really a Keplerian orbit; for the simple parabolic approximation found in first-year calculus texts is not adequate when the missile reaches 100-mile distances. Both the direction and the magnitude of the force of gravity vary sufficiently to give significant deviations from a parabolic trajectory. Assuming, then, coordinates and velocities determined by DOVAP for a point some 10 seconds after fuel cut-off, when there can be no question about any residual burning effects, we can compute an elliptical orbit. The coordinates of this orbit are given relative to a system of coordinate axes whose directions are fixed in space (Fig. 6). DOVAP-determined coordinates, on the other hand, are relative to the launcher, which is fixed on the surface of the earth but is therefore

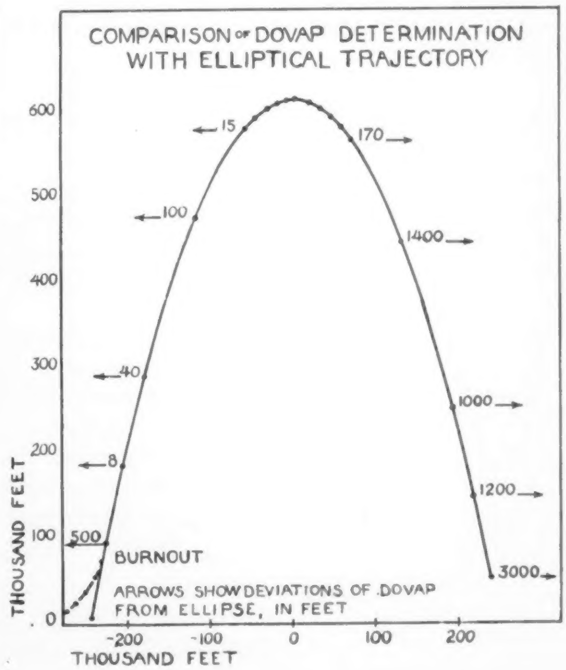


FIG. 7. The curve is an elliptical computed trajectory that depends on the observed trajectory data some ten seconds after burnout. The numbers and arrows show how well the complete observed trajectory agrees with the computed ellipse.

carried along an arc by the earth's rotation. (The earth's orbital motion we can still neglect!) Hence, for comparisons we must transform one system into the coordinate frame of the other (Fig. 7). Preferring the elliptical shape, we kept the fixed-space system and found the comparison shown in the last figure. The maximum altitudes, or maximum distances from the center of the earth, differed by only 200 feet; the greatest differences in the horizontal coordinate, occurring on the descending branch of the trajectory, amounted to approximately half a mile in forty. Other rounds gave comparable results; for poor DOVAP records the maximum altitude errors were of the order of a thousand feet.

As the discrepancies between observed and computed trajectories are scarcely greater than the inherent uncertainties of the reductions themselves, the comparisons suggest that accurate DOVAP reductions are essential only for the first 40-odd miles of travel, or to at least some 10 seconds after burnout. From the conditions observed at such points, computed trajectories should indicate the range to impact to the nearest mile. As the A-4 trajectories are very steep, the neglect of air resistance will not greatly influence the determination of the *horizontal* coordinate (though the drag could also readily be taken into consideration). On the other hand, the excellent agreement found in this analysis stimulates effort toward greater observational accuracy in order that DOVAP may develop into a more effective research tool—for example, for checking the properties of radio propagation, refraction, and other systematic physical effects.

FROM A MOUNTAINTOP

(IN AFTER YEARS)

JAMES G. HODGSON

I

Down from our heights were the "Plains of Man,"
Low in the foreground, high as they ran
Out there beyond where the sky began.

Rivers there were, with an upward tilt,
Winding their way in abandoned silt,
Wide in the basins that man had built;

Signs of the struggle that man had made
Taming the waters! The price he had paid?
How may we know how the balance weighed?

II

Here from the heights was the past in view,
Spanning the time when the dams were new,
Back to the days when the men were few.

Green was the ground as it lay below,
Lush at the distance, the winter's snow
Lives on the plains as the grasses grow.

Strong waxed the heat as the summer passed,
Dry was the earth, but the plants stood fast,
Holding the soil where their roots were massed.

III

Came then the men who would plow and sow,
Treating the grass as a common foe,
Baring the earth for the winds to blow.

Folly was theirs! Like a robber band
Sternly they reaped with a heavy hand,
Only to starve what they loved—the land.

Poor was the earth when the rains came not,
Poor was the man who received his lot—
Such of the soil as the wind forgot.

IV

Water! They wailed—and the Engineer
Throttled the streams, both far and near,
Bringing back life with a ditch and weir.

Great were the dams, and the world with awe
Marveled and cheered at the thing it saw
Sucking its wealth down a greedy maw.

Slowly the streams, with their loads of silt,
Twisted and turned where their burdens spilt,
Clogging the basins that man had built.

V

Down from the heights are the plains where man
Labored and toiled, when the waters ran
Deep in the ditches where farms began.

Gone are the fields where the plow bit deep.
Only the ghosts of the lost crops weep,
Waiting alone where the grass roots creep.

Low in the valley the bright streams run
Up toward the sky, but the timeless sun
Sees but the close of a cycle—done.

EFFECTS OF CERTAIN ANIMALS THAT LIVE IN SOILS

JAMES THORP

Located at the University of Nebraska, Professor Thorp is Regional Inspector of Soil Surveys for the Great Plains, Division of Soils, USDA. He has taught in Puerto Rico, in China (at Nanking University), and at Earlham College, his alma mater.

IN discussing the biologic factor of soil formation, textbook authors are accustomed to lay great emphasis on vegetation as it affects soil profile development and to give less space to the influence of animal populations in soils. During many years of field work I have been repeatedly impressed by the extent and magnitude of the modifications of soil profiles accomplished by animals that live in the soil. The effects superficially most noticeable are those brought about by the larger animals, such as burrowing rodents and carnivores; but in many places the smaller animals, such as worms, insects, spiders, crustaceans, and myriapods have made very marked changes in soils and have affected their characteristics more fundamentally than have the larger animals. Animals that live in the soil range in size from minute protozoa, visible only under the microscope, to burrowing mammals of quite large size (wolves, badgers, and large rodents). No attempt will be made to discuss in detail the effects of protozoa on the conversion of raw organic matter into humus, and, of course, effects of these animals on the microstructure of soils. Some conception of the importance of the microbial population (both protozoa and microscopic plants) may be seen in F. Garbrecht's note entitled *¿Cuanto pesan los microbios de la tierra?* ("How much do the soil microbes weigh?") He estimates a total weight of 2,000 grams per square meter of cultivated soil to a depth of 20 centimeters, or a little less than 18,000 pounds (9 tons) per acre in the topmost 8 inches. Of course, the weight of the microbial population will vary greatly with the kind of soil and other factors.

The importance of microscopic life is also brought out by A. G. Norman, who states that a substantial portion of the humified organic matter in soils is composed of the dead remains of microorganisms that feed on the residues of higher forms of life.

Among the most important visible animals that affect soil profile development are very small insects, such as springtails, mites, and celaphids that are abundant in the raw humus of the podzol soils; ants and termites, very active in many soils of the world; many small crustaceans, such as wood lice, or sow bugs; and millipedes, centipedes, and various kinds of spiders. Springtails and other minute insects consume the raw humus of the forests and convert it into new types of humus, the details of which have been covered by other workers (T. H. Eaton, Jr., and R. F. Chandler, Jr.) and need not be discussed here.

EARTHWORMS

In forested and cultivated soils, especially in soils of medium to heavy texture and where vegetation is of a type that is appetizing to them, earthworms are very active in converting raw vegetable matter to humus and in mixing the humus with the mineral portion of the soil. In many forested areas, and also in some grasslands, the superficial several inches of the soil consist almost entirely of earthworm castings that have given the soil a characteristic granular or crumb structure sometimes called "earthworm mull." This does not imply that all granular and crumb structures are due to the action of earthworms or other animals, but it is true that much soil structure originates in this way. In forested soils of some areas, especially in those of medium to clayey textures, it is conservatively estimated that 500–2,500 tons per acre of soil have been modified in structure and organic content by earthworms alone. Darwin estimated deposits of earthworm castings at rates of 7.5–18 tons per acre per year. A. C. Evans and W. J. Guild found up to 11.5 tons of castings per acre per year in pasture land, clay-with-flints soils, at Rothamsted Experimental Station, England. The same authors quote C. Beaugé as finding 107 tons of castings per acre deposited in the valley of the White Nile during one six-month rainy season.

In the spring of 1919, the earthworms were so abundant in the rendzina soils of the military parade grounds at Dôle du Jura in eastern France that the ground was almost covered with fresh castings. When soils were saturated following heavy rains, the worms were forced to the surface

by the water and could be heard withdrawing hastily into their burrows as one walked across the field.

Earthworms not only mix mineral matter with humus at the surface, but they also carry organic matter deep into the subsoil horizons and parent material when they retreat downward with the moisture during dry weather. Incidental to carrying organic matter to deep horizons and fresh minerals to surface horizons, they leave tunnels behind them that facilitate movement of water through the soils. In the course of studying cross sections of soils, I have seen water drip from earthworm burrows 2–3 feet below the surface when a pit was dug in Miami loam in southern Michigan soon after a rainstorm. Earthworm tunnels become coated with organic and mineral colloids and in many places provide passage space for roots through soil materials that are otherwise rather dense.

Earthworms have interesting methods of collecting food in forested areas. Apparently, Darwin was the first of recent times to discuss this subject in detail, and considerable work has been done still more recently on the Harvard and Yale forests in New England, in Ohio State University, and in England and other parts of Europe. These studies show that earthworms like to concentrate their activities in areas where plants are to their liking. For example, they like especially well the fallen leaves of ash, hickory, tulip tree, dogwood, large-toothed aspen, and several other species. Some kinds of earthworms go out during the night to gather up their favorite kinds of leaves and drag them to the mouths of their tunnels. They pull the leaves partially into the tunnels or heap them up around the tunnel mouths to form "earthworm middens" composed of petioles and other leaf fragments mixed with the feces of the earthworms (Fig. 1). In the early stages of development, middens comprise chiefly mounds of entire leaves and other plant remains.

Marked differences in organic content and structure of upper horizons of soils developed under hardwood cover versus those developed under coniferous forest are ascribed in part by P. R. Gast to differences in kind and degree of activity of the soil fauna. Referring to J. W. Johnston, he makes this statement relative to the preferences of earthworms for different kinds of leaves:

FIG. 1. *Left:* Earthworm middens on stony brown forest soil in the Yale Forest. Note tangled petioles heaped around burrows between rocks. Pencil, lower right, gives the scale. *Right:* Middens composed of earthworm feces and petioles of sugar maple, ash, tulip poplar, and linden leaves. Fox silt loam, deep phase, a gray-brown podzolic soil, at Earlham College, Richmond, Ind.

Of importance here are the observations by Johnston on the food preferences of the angleworm. He found that of six species studied in laboratory feeding experiments, the large-toothed aspen, white ash, and basswood were accepted immediately in that order. Sugar maple and red maple were taken less avidly; the latter was not entirely consumed. Red oak was not eaten.

It is indicated further that white-pine needles, in the field tests, were only 30 percent decomposed two seasons after falling, the assumption being that the earthworms probably refused them as food, and that other biotic factors were responsible for their slow disappearance.

B. G. Griffith and others found earthworms were always associated with soils of good tilth under hardwood forest cover and were generally absent in the soils of pine forests. Exception noted was in a twenty-year-old forest where the soil was formerly well cultivated.

Abundant earthworm middens were observed at Quaker Hill and at Earlham College (Fig. 1), Richmond, Indiana, in the autumn of 1941 and again in June 1947. They were especially plentiful under ash and sugar-maple trees on Fox silt loam, deep phase, that had once been cultivated. Under one large maple tree, at Quaker Hill in June 1947, my nephew and I counted 27–35 middens per square yard, or roughly 145,000 per acre. The middens were about ¾ by weight of worm feces and about ¼ by weight of maple-leaf petioles and grass stems. The total moist material in the middens from one square yard weighed 3.25 pounds—a rate of more than 15,500 pounds per acre. This material represented the work of the worms in late fall 1946 and spring 1947. In this period of about eight months the worms could have been active for no more than five months.

In Lewis Woods, a remnant of virgin hardwood forest in Wayne County, Indiana, I. C. Brown and I noted in 1939 that the Miami silt loam there has a crumb-mull horizon, 1–4 inches thick, made up largely of earthworm castings and feces of other small invertebrates. Organic matter was high in this layer (6.2 percent), and the reaction was only slightly acid. Assuming an average thickness of 2 inches, this mull horizon represents about 56,000 pounds (28 tons) per acre total, of which about 3,500 pounds (1.75 tons) is humified organic matter, totally reworked by earthworms and their associates. This topmost 2 inches is only a fraction of the total soil in the profile that has been permeated and mixed by earthworms.

It is not necessary to assume that the worms have added any new material to the soil in this instance; but it is obvious that they have facilitated the conversion of raw organic matter to humus and have been instrumental in mixing the humus with soil minerals. Homer Hopp and H. T. Hopkins have demonstrated that earthworms add little or no new plant nutrients to the soil in which they live and grow; but their dead bodies, if added in large quantities to infertile soils, will nourish the plants in these soils.

In an oak-hickory forest of northern Indiana I once noticed that the earthworms had selected hickory leaves to the almost complete exclusion of oak leaves. In June or early July practically all the dead leaves remaining scattered evenly over the surface in this forest were of oak; the earthworm middens were made up almost entirely of petioles and other remnants of hickory leaves mixed with worm feces. The worms have a similar appetite for ash, dogwood, and some other species. Certain earthworms will eat oak, pine, and other leaves, but generally are not very abundant in the dense oak and pine forests of eastern United States.

There is evidence, not yet fully conclusive, that the palatability of vegetation to earthworms depends somewhat on the mineralogical composition of the soils. Well-nourished trees seem to have more palatable leaves than undernourished ones of the same species.

Earthworms are also very active in some prairie and chernozem soils, where they play an important part in mixing organic and mineral soil constituents and in the development of granular or crumb structure. Even in desert regions they soon become abundant when moisture conditions and food supply are improved by irrigation.

Earthworms do not always improve the structure of soils they inhabit, however. For example, A. Leahey, Head of the Dominion Soil Survey Staff of Canada, told me that soils of Alberta and Manitoba were damaged by earthworms that were introduced. Under virgin conditions, the highly fertile chernozem soils of Alberta, Saskatchewan, and Manitoba had no indigenous earthworms. Dr. Leahey made the following statement on the subject in a letter dated November 22, 1948:

> About 1931 I visited a farm north of Edmonton with J. D. Newton. While there, the lady of the house asked us how to get rid of earthworms, as they had ruined one garden for her in a matter of two years and were rapidly ruining a second one. Her story was that the earthworms had turned the soil into a sticky, plastic mess. The soil was a Chernozem clay which normally had a good (granular) structure. Earthworms had a deleterious effect on the physical condition of the Chernozem clay soils. Instead of being improved, the granular friable clay broke down into a sticky mass that was extremely difficult to manage after the earthworms had multiplied sufficiently to have a noticeable effect.

R. L. Pendleton has made some observations on the activities of earthworms in certain tropical areas. In Siam, for example, earthworms attain a length of a foot or two and seem to prefer to live in imperfectly drained soils that have been highly leached and are very infertile. In contrast, dense colonization by earthworms in the United States usually is interpreted to be a fair indication of medium to high soil fertility. Pendleton states that the earthworm mounds of Siam, composed mainly of the feces of these animals, are as much as a foot high and a yard across. Fresh earthworm mounds may be chimneylike in form, similar to those built by crawfish and crabs in the United States and the West Indies.

W. M. Johnson writes (October 21, 1948) from Colombia, South America:

> . . . you will be interested in the macro-fauna of these soils . . . , especially the earthworms. There are at least two species in the region, some relatively small that build towers up to about three inches high, with their casts—like miniature crawfish deposits; the other worms are big, up to a half inch in diameter and at least 18 inches long. Photos show the earth's surface to a depth of ¾ inch completely covered with casts from these big worms.

He goes on to say that, in spite of their hardness, the casts break down rapidly when the rains come, and he infers that the fresh castings are all of the current season. With two wet and two dry seasons each year, one may assume that the worms till the soil to a depth of at least 1.5 inches each year.

INFLUENCE OF ANTS

Estimates of insect and other invertebrate fauna populations at Rothamsted by H. M. Morris gave a total invertebrate fauna of 15,100,000 per acre of land that received 14 tons of manure per year for about seventy-eight years. Of this population, 7,720,000 were insects. A plot that had been unfertilized for eighty-two years had an invertebrate fauna population of 4,950,000, including 2,470,000 insects. Observations on a pasture plot in Cheshire by the same author revealed an insect population of 3,586,088. These figures give an idea of the order of magnitude of animal populations in soils. Most soil invertebrates are short-lived; a large proportion of them die and return the organic matter of their bodies to the soil within a year and in some instances in much less than a year. It takes a large number of most insects or of the other very small invertebrates to make a weight equal to one field mouse, but the vast numbers and rapid turnover of population among the invertebrates probably more than offset the differences in weight of individuals.

The ants are among the most interesting of the insects, so far as soil formation is concerned. They are of many different species, each of which has its characteristic habits and habitats. W. P. Taylor and W. G. McGinnies state:

> Everyone is familiar with the earthworm's outstanding reputation as a soil maker. That other animals play an important role is doubtless not so widely appreciated. Yet Shaler in his paper on "The Origin and Nature of Soils" says that ants produce a far greater effect on soils than earthworms. Shaler thinks the vertebrates exercise an influence on the soil perhaps as great as that of all their lower kindred.

The leaf-cutting ants march for long distances, cut out fragments of leaves and stems of plants that are to be used directly or indirectly for food, carry them back home, and store them in underground chambers. Here they are used to produce fungus that is in turn used for food. In this way organic matter, both in the forests of Central America and in the brushlands of northern Mexico and Texas, is incorporated in the soil and converted to humus through the activities of fungi (planted by the ants) and by the deposition of fecal matter by the ants themselves. In a private communication, R. L. Pendleton reports that mounds of these leaf-cutter ants in Central America frequently are as much as 15 feet across and 3 feet high. I have seen smaller ones in the brushy lands of south Texas. The mere tunneling operations of these ants have the effect of moving mineral material from one horizon of the soil to another, and after the anthills are abandoned the chambers provide channels for rapid water penetration to the deeper subsoil horizons.

Throughout the greater part of the subhumid and semiarid portions of the United States there is a large red ant (perhaps of more than one species) which builds a chambered nest beneath the surface of the ground and a conical mound of excavated material above the surface. The mound is riddled by chambers used for the storage of food and the rearing of the young. Many who read this doubtless are familiar with the anthills scattered over tremendous areas of the Great Plains and in the deserts and intermountain valleys of the United States. Somewhat similar anthills occur in the humid sections of the country. I have made conservative estimates of the amount of soil material in the anthills of representative areas of the Western plains. The figures for the amount of material affected are based on a conservative estimate of the average-sized anthill and of the number of anthills per acre in some parts of the country. The anthill in the photograph (Fig. 2) has a volume of approximately 1.9 cubic feet of fine earth mixed with coarse sand and fine gravel

brought up from subsoil horizons. Some of the fine gravel may have been gathered from the surface in near-by areas. It is used by the ants to form a sort of pavement or roof over the hill. If we estimate that one cubic foot of earth will weigh approximately 90 pounds, then the individual anthill will probably contain about 170 pounds of soil material. If, as is not uncommon, there are 20 anthills per acre, about 3,400 pounds of earth will have been piled up on the surface by the ants. This material is removed largely from subsoil horizons, with the net effect of rejuvenating the soil by bringing up fresh material to the surface from beneath. To be sure, the number of large anthills in much of the Great Plains is less than 20 per acre, but it is also true that some anthills are destroyed every year and new ones are built on different sites so that the effects over a long period of years are very great. In addition, many small anthills built by other species, are not counted in this estimate (Fig. 2).

An aerial photograph (Fig. 3) taken in Kiowa County, Colorado, shows about 400 anthills on a selected 40 acres of land. Doubtless many exist that do not show on the photograph. An oblique aerial photograph (Fig. 4) taken northeast of Denver, gives a closer view of clearings made by ants. The hills are visible on aerial photographs because the ants have cut all vegetation from around each hill in a circle, the diameter of which varies ordinarily from hill to hill from about 6 to 20 feet. The bare earth reflects the light and

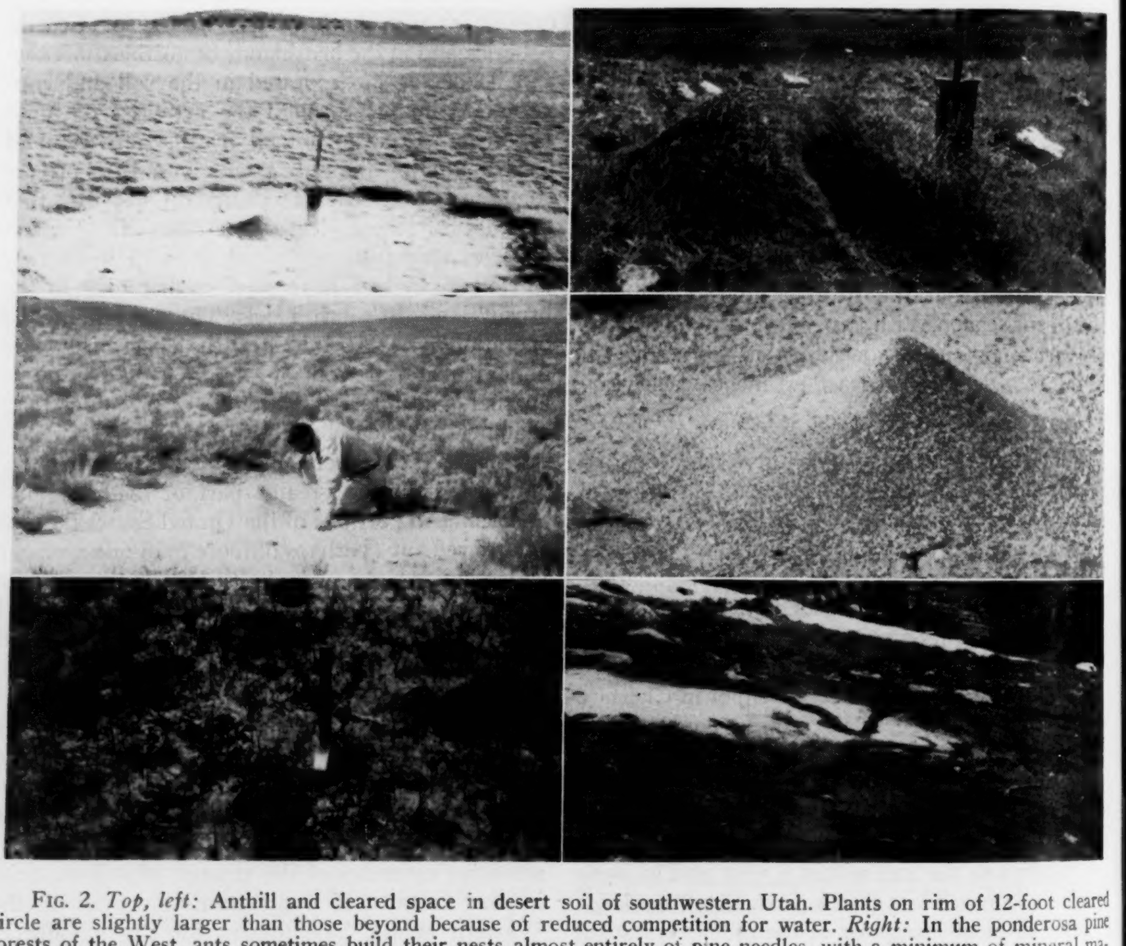


FIG. 2. *Top, left:* Anthill and cleared space in desert soil of southwestern Utah. Plants on rim of 12-foot cleared circle are slightly larger than those beyond because of reduced competition for water. *Right:* In the ponderosa pine forests of the West, ants sometimes build their nests almost entirely of pine needles, with a minimum of mineral material. When these are abandoned, they leave a concentrated supply of organic matter on the soil.

Center, left: Anthill on sierozem soil in Sevier County, Utah. *Right:* Close-up of same anthill, showing fine-gravel roof with which the ants protect their homes. The fine gravel is eventually incorporated into the A soil horizon.

Bottom, left: Geologist's hammer near center shows, by comparison, small size of one kind of anthill scattered through the United States. (Anthills outlined in black for clarity.) It was estimated that small ants piled 500 pounds per acre of sandy material on the surface at Archer, Wyo., within a few days' time. *Right:* Melting snow reveals "roll" of earth made by small burrowing mammals in the Medicine Bow Mountains, Wyo. Rolls soon break down and are incorporated in the A horizon.

makes a whitish spot on the picture in each case. In some instances the hills are so close together that the bare spots merge and it is impossible to distinguish one hill from the next on small-scale aerial photographs. The largest mound I have observed so far was seen in the semidesert country of Duchesne County, Utah, where an anthill estimated to contain 300 pounds of earth was surrounded by a cleared area 40 feet in diameter.

Ants seem to prefer somewhat sandy and fine gravelly soil materials, probably because they can find suitable gravel for roofing their hills. I have seen anthills on the Houston and Wilson soils of Texas, however, where practically no satisfactory grit is available. There, the ants bring up balls of limy material from below ground and deposit them at the surface in lieu of fine gravel, thus tending to maintain a neutral or alkaline reaction in the surface soil.

Fragments of vegetation cut from the surface and removed to the anthills are eaten by the ants or stored in bins or granaries for future use. Commonly, great masses of seeds are stored in some of the bins of these anthills, presumably for use during the season of the year when vegetation is scarce. These materials are converted gradually to humus in the soil through the action of fungi and digestion by ants. The earth in anthills built on fine-textured soils frequently has a fine-granular structure induced by the activity of earthworms that feed on the organic material stored by the ants.

Clearings made by ants leave the soil exposed to erosive effects of wind and rain. On the older anthills one finds a slight depression around the mound itself where wind and water have removed the soil material; and small mounds of earth have collected around clumps of vegetation in the vicinity (Fig. 2). In this way soils are truncated and rejuvenated, little by little.

TERMITES

Termites have been studied to a limited extent by various soil scientists, especially in the tropics. G. Milne, of Africa (now deceased), Pendleton, formerly of Thailand, and G. Aubert have done some work on this problem. Some of the termite mounds are as much as 6–10 feet high and perhaps as much as 20–40 feet across. The termites gather vegetation from the soils of the neighborhood and carry it to their nests, where it is used for food either directly or for the cultivation of edible fungus. On some of the old strongly leached and

FIG. 3. Vertical aerial photo of ant-infested grassland area southeast of Denver. Minute light-gray specks represent circular bare spots where ants have harvested all vegetation. The 40 acres with cross lines are estimated to have about 400 anthills.

weathered soils of East Africa, Milne found that soils on certain plains where termites were active contained only a small trace of calcium, but that the soils in the termite mounds were very high in calcium; in fact, some of the mounds were calcareous throughout and had great masses of impure limestone (*caliche*) at the centers, which may possibly have formed through the hardening of lime left as a deposit from the waste matter from plants. It seems a reasonable hypothesis that over periods of centuries, and perhaps hundreds of centuries, the termites have gradually accumulated in their mounds practically all the calcium from the soils of the neighborhood by harvesting nearly all the vegetation that came up and carrying the calcium to the mounds in the form of organic matter. Milne suggests a few alternative hypotheses for the accumulation of lime carbonate, one of which is that the termites bring it up from deep substrata to use as cement.

Pendleton has raised the question, without solving it, as to why the termite mounds contain such a large amount of calcium without any apparent similar accumulation of phosphates. He reports that in Thailand a practical advantage was taken of the work of termites in accumulating calcium in the soils. Over a large area on the plains of Thailand most soils have been so highly leached and weathered that crop production on them is

almost out of the question without heavy fertilization. The soil supports only a scrubby growth of forest trees except in the vicinity of these ancient termite mounds. Here the *p*H is higher and the fertility is sufficient for the people to use the earth in the mounds as soil, and they can raise various food crops and tobacco with little fertilization. The termite mounds are partially leveled and used for farming, whereas the ancient soils between them are used only when heavy fertilization is possible. The process of leveling must be spread over a period of years in order to incorporate organic matter in the material of the lower horizons of the mounds. One could mention further that termites in the Temperate Zone of the United

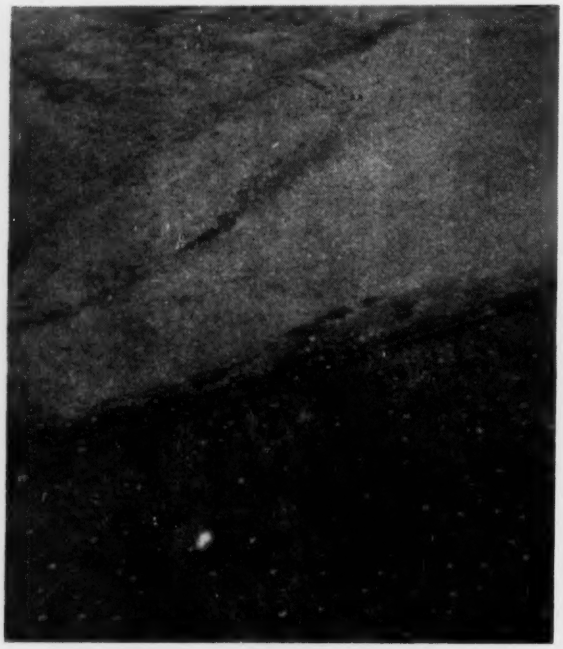


FIG. 4. Oblique aerial photo shows circular anthill clearings, 6–20 feet in diameter, on brown soils northeast of Denver.

States perform the function of converting wood into humus in the forests and, unfortunately, in in our homes also if we are not watchful.

Milne noted that native farmers in East Africa took similar advantage of fertility stored in termite mounds. He calculated that the mounds contain enough calcium carbonate to make a heavy lime application to the leached soils between them and recommended this as an agronomic amendment for some of the infertile soils of the region.

In a personal communication Aubert described termite mounds of several types in the French Sudan, French West Africa, and along the Ivory Coast. He states that some mounds contain concentrated lime carbonate, like those described by Milne, and some do not. All representatives from Africa at the 1948 Commonwealth Conference on tropical soils at Rothamsted mentioned the activities of termites in soils of Africa.

Wood lice, millipedes, centipedes, and spiders all affect soil profile development, especially to the extent that they consume organic matter of various sorts and convert it into other forms of humus. In forest soils the A_1 horizon in many places consists almost entirely of feces of these small animals mixed with those of earthworms. Some of this material retains its original form for a long time and imparts to the soil a characteristic and persistent very fine granular structure.

CRUSTACEANS

Large crustaceans, including crabs and crawfish, are very active in soils where the water table is within a few inches or a few feet of the surface. I have observed the activity of land crabs, especially in the West Indies, where they inhabit low swampy and marshy areas adjacent to the sea and build tunnels from the surface down to the water table. At night they bring up balls of earth tunneled from beneath and deposit them in the form of chimneys at the surface. In sugar-cane fields cultivation breaks down the chimneys and partially refills the burrows, which are cleared out again the night after the land is cultivated. An enormous amount of earth is thus kept in circulation. The crabs feed on vegetation, and possibly on carrion, and of course mix this organic matter with the soils. Incidentally, they are a great pest in cane fields and are poisoned systematically by agriculturists, or are trapped and used as food by the people.

Crawfish range in size from very small up to perhaps as much as one foot long. They are active in poorly and imperfectly drained soils from the Gulf Coast north to the Canadian border. They are especially active in the southern part of the gray-brown podzolic soils zone and throughout the zone of red and yellow podzolic soils, but they confine their activities largely to soils of the planosol, wiesenboden, and half bog groups. They build chimneys on the surface much like those made by the crabs. Chimneys on planosols in southern Indiana measure as much as 8 inches in height and about 4–8 inches in diameter (Fig. 5). The crawfish work at night, bringing mud from deep underground. Some of the vertical tunnels beneath the chimneys are as much as 15 feet deep, because the crawfish must have contact with the water table at all times. Their tunnels penetrate the clay

pans of the planosols, facilitating upward and downward movement of water, and they bring fresh soil material to the surface from great depths. The importance of their activities can be estimated from the photographs in Figure 5.

In one area studied in southern Indiana, a large chimney occurred about every 5–10 feet in each direction; all the chimneys had been built by the crawfish after the corn had been planted (Fig. 5). At the time this area was studied the corn was just ready for its first cultivation. Tunnels to the water table were about 10 feet deep. If one examines a field in which all chimneys have been destroyed by cultivation, one will find that a whole crop of new chimneys will have been built up a few days after the field is cultivated, as in this instance. The activity is especially great during the spring when there is plenty of moisture in the soil. Where crawfish chimneys weigh 3 pounds each and 625 of them occur per acre (1 every 8 feet in each direction), the total weight of earth heaped on the surface would be a little less than one ton per acre. If chimneys occur every 5 feet in each direction, the total weight would be a little less than 2.5 tons per acre. Perhaps the chimneys would be destroyed and rebuilt three or four times in one season, and 3–10 tons of earth would be moved. In 1946 E. Templin, H. Oakes, and I noted small crawfish chimneys on Beaumont clay in east Texas spaced so closely that there were 20,000–50,000 of them per acre in areas of greatest concentration. The water table was only a foot or two below the surface.

One lasting effect of the activities of crawfish and crabs can be seen in very old soil profiles in certain red podzolic soils of southern Alabama. At Grand Bay, in Mobile County, a group of us studied a railroad cut through a low ridge on which there was a red podzolic soil with an incipient lateritic hardpan 2 or 3 feet below the surface. In this cut were several "fossilized" crawfish tunnels which extended from approximately the surface to a depth of 6 or 8 feet in the cut. The tunnels were lined with hard limonite to a thickness of about 0.5 inch, and the interiors were filled with clayey material. Each tunnel terminated at the bottom in an ovate chamber about 6×10 inches. It must have been thousands of years since this particular set of tunnels was made by the crawfish, because the water table has long since retreated many

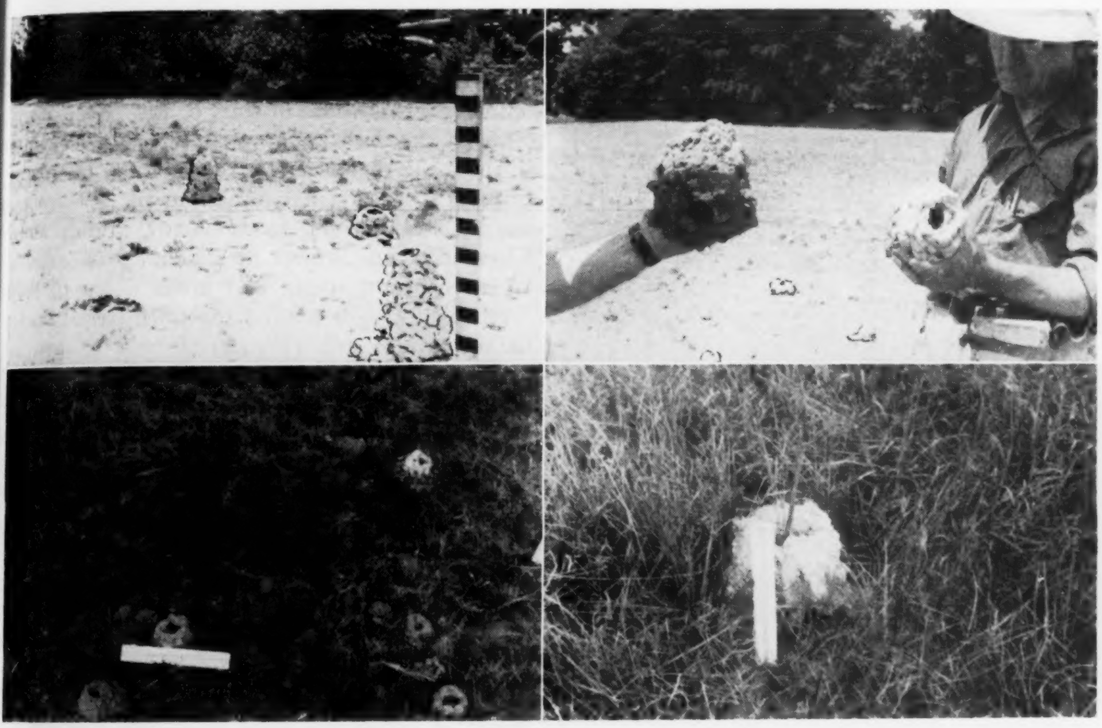


FIG. 5. *Upper left:* Crawfish chimneys in field of very young corn, on Robinson silt loam, a planosol of southern Indiana. (Photo retouched to accentuate three of the chimneys.) *Upper right:* Close-up of two crawfish chimneys. *Lower left:* Abundant small crawfish chimneys on poorly drained Plummer fine sandy loam, Beauregard Parish, La. Scale is 7 inches long. *Lower right:* Single crawfish chimney on Caddo fine sandy loam, same Parish.

FIG. 6. Profile of Marshall silt loam, a prairie soil of southwestern Iowa, shows dark blotches in deep subsoil where a gopher burrow has been filled by dark earth from the A horizon.

feet below the bottoms of the chambers. The fossil crawfish tunnels are in a remnant of a former ground-water laterite soil which formerly extended over a considerably greater area than it now does. In recent times it has been converted to a red podzolic soil following a lowering of the water table brought about by dissection of the land. The soil occurs on the highest Pleistocene terrace remnant.

OTHER ANIMALS

Burrowing mammals and, in some instances, amphibia and lizards are important factors in the rejuvenation of soils in many parts of the world. Their activities are especially noticeable in grassland areas of the Great Plains and in the deserts and semideserts where prairie dogs, gophers, and other rodents are very abundant and active; but the total effects are probably just as great, though less noticeable, in forested areas. These animals burrow through the entire *solum* and well into the parent material or substrata beneath the soil, and parts of all horizons and underlying materials are brought to the surface and there thrown out as a heterogeneous mixture. In some prairie-dog towns almost the entire soil has been completely churned and rejuvenated by the activities of the animals. Prairie dogs frequently build their towns in places where subsoil horizons are clayey, and in some instances they select areas of solonetz or solodized solonetz for their homes. Their activities tend to destroy parts of the clayey layers and to heap fresh limy or salty material on the surface.

Figure 6 shows how rodent burrows in deep subsoils become filled with dark soil from surface soils of the prairie, chernozem, and chestnut soils zones. J. E. Weaver, of the Botany Department, University of Nebraska, tells me that he always finds burrow fillings in excavations made for studying grass roots in soils of the Great Plains. This checks with the experience of soil scientists in the same region. Some of the small burrowing mammals bring soil materials to the surface and use it as backfill when they burrow in deep snow. These peculiar "rolls" of material are exposed when the snow melts, and break down to form "ribbons" of light-colored subsoil material on the darker surface soils (Fig. 2).

In May 1947, L. T. Alexander and I estimated roughly the amount of earth that burrowing animals had piled on the surface or mixed with the surface soil of Rago silt loam at the Dry Land Experiment Farm, Akron, Colorado. We measured off a 4-acre plot of land in a virgin pasture where sandy and gravelly mounds marked the former dwellings of prairie dogs and badgers (Fig. 7). Sixty-nine mounds were counted in the 4 acres, an average of about 17 per acre. A deep excavation showed the original soil to be developed from calcareous loess, of silt loam texture, that overlies strata of gravel and sand at depths ranging approximately 6–10 feet. In the course of soil formation the lime carbonate has been leached out to depths ranging from about 14 to 20 inches. That all the burrows had reached down as far as the sand and gravel layers is proved by the preponderance of sand and gravel in the mounds. The undisturbed soil contains no gravel or medium- or coarse-grained sand. Two of the several large mounds measured proved to have a maximum thickness of 18–19 inches and a diameter of 24 feet. For convenience in estimating the volume it was assumed that the mounds were conical in shape, an assumption that will give a conservative estimate of the volume of the mound. The volume of a cone is calculated as follows:

$$V = \pi \frac{r^2 \times h}{3}$$

where r is the radius of the base and h is the alti-

tude of the cone; substituting measured values for r and h,

$$V = \frac{\frac{22}{7} \times 12^2 \times 1.5}{3} = 226.3 \text{ cubic feet.}$$

One cubic foot of dry loam or sandy loam, with some gravel, will weigh about 100 pounds. The weight of the mound is therefore about 22,630 pounds, or 11.3 tons. By similar methods, weights of mounds of several different sizes were estimated to range from a minimum of 210 to the maximum of 22,630 pounds given above.

Estimating the average size at 3,770 pounds, we obtain a total weight of 130 tons for 4 acres, or 32.5 tons for 1 acre. By another method of estimating we get a higher figure (Table 1).

TABLE 1

No. of Mounds of Given Size	Weight of Each Mound	Total Weight in Pounds
10	22,600	226,000
15	3,850	57,750
24	1,000	24,000
20	210	4,200
		311,950

This is equivalent to 156 tons on 4 acres, or 39 tons on 1 acre. Thus we may say conservatively that the burrowing animals have brought 30–40 tons of mixed sand, gravel, and subsoil material to the surface. Much of this came from a depth of 8–10 feet underground.

Near the same place, we counted 50 fresh mounds in a prairie-dog town on one measured acre of land (Fig. 8). The mounds ranged from 2 feet in diameter, 6 inches high, to 18 feet in diameter, 18 inches high. Some of these mounds were largely gravel and sand; others, where the loess is thicker, were almost entirely of yellowish calcareous loess of silt loam texture. On this acre of land a calculation based on the weight of an average mound gives a total of about 22.5 tons of earth piled on the surface.

On this field the prairie dogs were keeping the grass, largely western wheat (*Agropyron smithii*) and blue grama (*Bouteloua gracilis*), cut close to the ground. Heaps of rodent manure were piled around the borders of the mounds; and these, with the urine from the animals, were serving to fertilize the next crop of grass. One of the characteristic phenomena around old mounds is the dark-green color of the vegetation—evidence of abundant nitrogen.

Surface soils on about one third of the experimental plots at the Akron Station have been converted from silt loam to loam through the activities of rodents and badgers. Apparently a colony of these animals lived here before the station was established. Subsequent tillage operations have thoroughly mixed the gravelly and sandy materials of the mounds with the original silt loam surface soil. The thickness of loess and soil over stratified sand and gravel on the plots, where measured, ranged from about 6 to about 10 feet.

The common pocket gophers and ground squirrels of the Great Plains appear in large colonies from time to time. In 1947 Earl D. Fowler and I made some measurements of earth moved in a few weeks by a colony of gophers at Lincoln, Nebraska (Fig. 8). We calculated that 56,000 pounds, or 28 tons, of earth had been piled up by these animals on one acre. The smaller mounds weighed about 15–20 pounds each, and the largest was estimated to weigh 400 pounds.

This brings to mind the paper by V. B. Scheffer on the Mima mounds of western Washington.

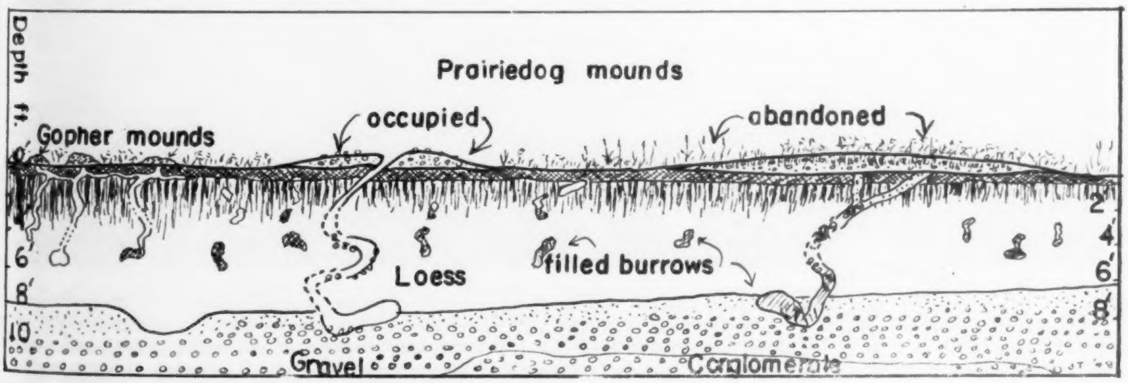


FIG. 7. Diagram of Rago soils on virgin pasture land of the Dry Land Experimental Station, Akron, Colo. Rago silt loam occurs between the mounds built by small mammals. Soils on the mounds contain a mixture of silt loam with sand and gravel brought up from deep substrata. In adjacent cultivated fields most of the mounds and intervening soils have been mixed to form Rago loam. Note dark earth in vacated burrows.

Scheffer suggests that these phenomenal mounds, and possibly the famous San Joaquin soil mounds of California, are the work of gophers. R. C. Roberts and W. J. Leighty, of the Division of Soil Survey, and L. C. Wheeting, of Washington State College, visited the mounds with me in September 1948, and we found it difficult to suggest any other satisfactory explanation for their development. The soils on these mounds are very gravelly and contain a high percentage of black humified organic matter. The black horizon is more than 30 inches thick on many of the mounds, which is much thicker than in most prairie soils of normal development, and lends weight to Scheffer's hypothesis. Figure 8 shows some mounds in Montana that are similar to the lower of the Mima mounds.

Where rodent colonies become too dense, most of the vegetation is destroyed and erosion may be accelerated. A particularly noteworthy example of this was seen on the Tibetan borderland and reported to me by a Chinese scientist, C. C. Ku, who traveled in that region. In this area certain burrowing rodents had become so abundant that all the soil was honeycombed by their burrows. Yaks and other domesticated animals, pastured in these areas, broke through the tunnels and exposed the soils to wind and water erosion. In some places all the soil was swept from large areas of hillsides in this region.

With reference to burrowing animals, Taylor states:

> Mice and other burrowing species, notably the pocket gopher, in many of the forests of the West are continually cultivating the soil, letting in water and air, carrying down vegetation, bringing up earth, in general helping the great soil complex to function. There is little doubt that all these creatures have their place in maintaining the natural equilibrium between soil, climate, plants, and animals.

Field and woods mice, moles, and shrews have intricate systems of tunnels in the soils of forests and grasslands. Ground squirrels and gophers are so abundant in some places (e.g., south Texas) as to turn over 15–20 percent of the surface soils in a single season. Kangaroo rats and other burrow-

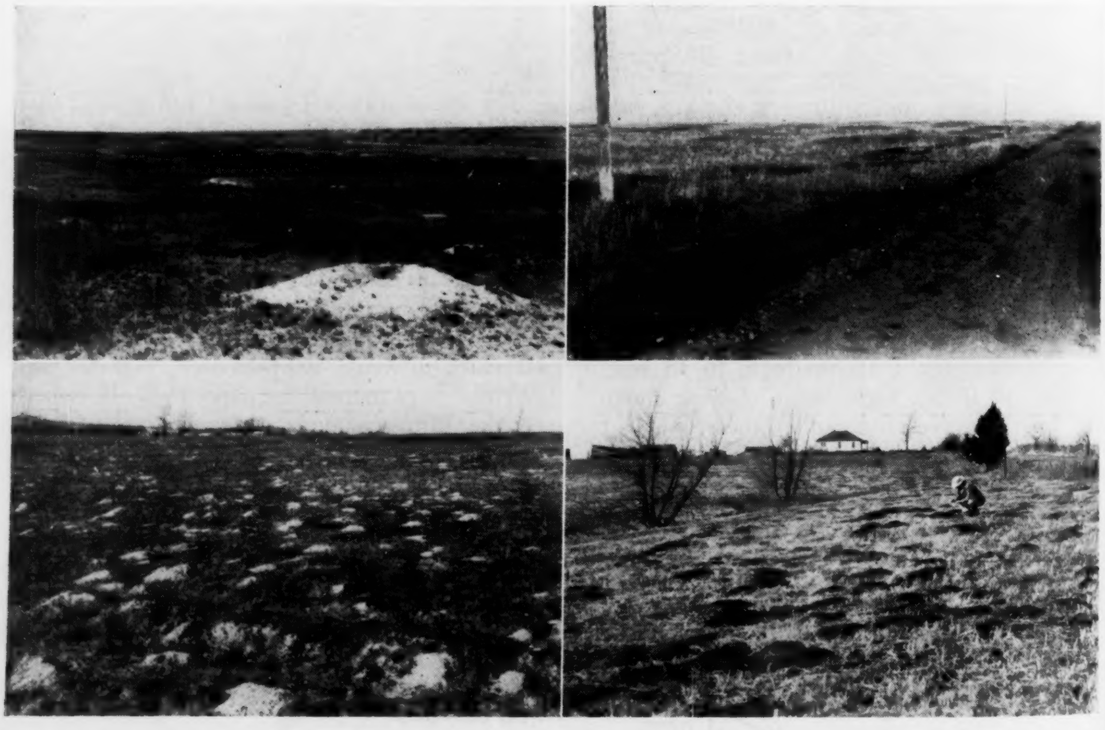


FIG. 8. *Upper left:* Prairie-dog mound, Akron, Colo., about 8 feet in diameter and 10 inches high. Mound contains much sand and gravel, whereas surrounding soils do not. *Upper right:* Low, broad mounds on chestnut soils on a high terrace, 10 miles west of Wisdom, Beaverhead Co., Mont. An intimate mixture of silt loam, gravel, and organic material, the mounds resemble the lower of the Mima mounds of western Washington. Burrowing rodents are very active in them.

Lower left: Small gopher mounds southeast of Lincoln, Nebr., made in autumn 1947. Total earth piled on surface is about 56,000 pounds (28 tons) per acre. (Photo by W. M. Johnson.) *Lower right:* Gopher mounds in deep sandy soils of Cherokee County, Texas, tentatively correlated as Eustis loamy fine sand. About one third of surface soil has been "plowed" in one season (fall-winter, 1947–48).

ing mammals in desert and semidesert regions either build mounds 6–10 feet in diameter and 1–3 feet in height, or build their homes in sandy mounds developed by wind action. In some places the colonies of the kangaroo rats make up fully 30 percent of the land surface. Taylor records as much as 12.5 pounds of sections, crowns, and seeds of grasses stored by kangaroo rats in one burrow.

One might go on to enumerate many other kinds of animals that burrow in the soils and bequeath their waste materials and dead bodies to the organic component. Suffice it to say that the animals that live in the soil in many places are almost as important in the development of soil profiles as the vegetation of the region. If we consider the effects of all land animals on soils, we may say that animals as a whole probably are as important in soil profile development as vegetation, except, of course, that animals cannot exist without vegetation. Doubtless we should have soils if there were no animals, but we could not have soils without plants. It is to be hoped that in the future more soil research will be directed toward the investigation of the influences of animals on soil character. Truly, the biological factor of soil formation *is* a *biological* one, involving symbiotic and antipathetic relationships among animals and animals, plants and plants, and among plants and animals.

SCIENCE, THE ENDLESS FRONTIER

Atomic Clock

The National Bureau of Standards has announced the development of a new primary standard of frequency and time, invariant with age. This is the atomic clock, based on a constant natural frequency associated with the vibration of the atoms in the ammonia molecule. The improvements in frequency and time measurement are expected to alleviate the crowding of the radio spectrum, to aid in astronomical measurements, to facilitate long-range radio navigation systems, microwave spectroscopy, and the like.

Electronic Letter Reader

Developed for the use of the blind, the laboratory model of an electronic device that converts printed letters into actual sounds was exhibited recently at the Museum of the Franklin Institute. The device, designed for institutional use at the suggestion of the Office of Scientific Research and Development, is large and costly. According to the Franklin Institute *News:* "As the user moves the scanning device along a line of type, a miniature cathode-ray tube explores each letter with eight spots of light arranged in a vertical line. When the spot of light passes over any black portion of a letter, an impulse is sent to the selector unit. There impulses are counted electronically. After the letter has been completely scanned, the total number of impulses is noted by the selector unit. This number, which is unique for each letter, actuates a magnetic tape recording of that letter, and the audible sound is reproduced through the loudspeaker."

Ancient Book

A papyrus estimated to be 3,600 years old, "the oldest scientific book in America and the oldest nucleus of really scientific knowledge in the world," has been presented to the New York Academy of Medicine for its rare book collection. Gift of the New York Historical Society and the Brooklyn Museum, the *Edwin Smith Papyrus* is divisible into three parts: the first and most valuable deals with 48 surgical cases, each of which is methodically presented, with explanatory comments added by later contributors; the second is entitled "Incantation of Expelling the Wind of the Year of Pest;" the third, "Incantation of Transforming an Old Man into a Youth of Twenty."

Rocks

Two tons of rock samples, drilled from beneath the surface of Funafuti Atoll more than fifty years ago by British and Australian scientists, have been lent by the British Museum to U. S. scientists for extensive study. They are housed at the National Museum in Washington side by side with other specimens from Bikini. Experts hope eventually to solve the mystery of the geologic past of the Pacific's thousands of atolls.

ON DEFINING "SCIENCE"

A. CORNELIUS BENJAMIN

Dr. Benjamin (Ph.D., Michigan, 1924) is John H. Lathrop professor of philosophy and chairman of the Department at the University of Missouri. He has taught also at Illinois and Chicago and studied in France and England as a Guggenheim Fellow. He is the author of The Logical Structure of Science *and* Introduction to the Philosophy of Science, *as well as of numerous educational and philosophical articles.*

IT IS no easy task to define science. There are at least two reasons for this. In the first place the word has had a long and complicated history. As a result it has taken on a great variety of meanings, often inconsistent with one another. In the second place, and much more important, it has recently become a term of praise; since science is the "best" way of doing things we demand that advertising, detective stories, social planning, and even religion itself be scientific in method and intent. As a consequence the term has become dangerous because of its misleading associations; when anything calls itself "science," beware!

The problem is further complicated by the fact that every definition is, as everyone knows, to a certain extent arbitrary. One can, like Humpty Dumpty, make words mean exactly what he chooses to have them mean. But all of us, no doubt, feel the social pressure of conventional usage. When Eve saw Adam for the first time, as Mark Twain tells us in *Eve's Diary,* she decided to call him a "man." Why? Because he looked like a man. If as members of a social group we are to use the word "science," we ought to apply it to something that *looks* like science.

Two definitions that are in common use seem to confuse rather than clarify the issue. One of these identifies science with something that is commonly called the "scientific spirit." This, in turn, is defined rather vaguely as a way of looking at the world which is characterized by impartiality, freedom from prejudice, and respect for the criteria of truth. The scientist seems to feel to a very high degree his responsibility to the ideal of knowledge, and cautiously avoids temptations to fall into wishful thinking, or to be duped by his senses, or to accept superstitions or unsupported authority as adequate knowledge. Science, then, can be defined as any study that is characterized by objectivity, unemotionality, rigor, and control.

The other definition swings as far in the opposite direction; it identifies science with the quantitative method as applied in laboratory and experimental techniques. This is in accord with the traditional picture of the scientist, who is commonly represented as a white-coated individual surrounded by test tubes, flasks, and intricate mechanical contrivances. Science, according to this conception, first became scientific when it abandoned purely observational techniques and substituted, on the one hand, manipulatory acts that involved setting up situations not normally occurring in nature apart from human intervention, and, on the other, instrumental aids to increase the range of the sense organs and to render measurement operations more precise.

Both these definitions are perfectly satisfactory if one is willing to accept the consequences of their usage. According to the former, of course, much will be science that is not commonly called by this name—philosophy, history, all the social studies, theology, and many authoritarian studies which, at least within the framework of their method, may be pursued with true regard for the principles of objectivity and control. According to the latter, much will not be science that is commonly called by this name—mathematics (which has no laboratory and performs no experiments); astronomy (which, though it uses instrumental aids, has no laboratory and performs no experiments in the strict sense of the word); theoretical mechanics (which is no more experimental than is geometry); and much of biology and psychology (which are highly restricted in their use of quantitative techniques). If one wishes, therefore, to win friends and influence people he has only to adopt the former definition, according to which he will be in a position to call practically everyone scientific, thus distributing honors widely. If, on the other hand, he is not averse to making enemies, he has only to adopt the latter definition, according to which very few of his associates will be entitled to the dignity of the name.

A much happier procedure, presumably, would

be to choose a definition somewhat less broad than the former and somewhat less narrow than the latter. We do not gain in the understanding of a term if we define it so that everything falls under it or so that nothing falls under it. I propose, therefore, as a compromise, that science be defined as "the method of verified hypotheses."

Without further discussion and clarification, however, such a definition carries no enlightenment whatever. We define only when we equate notions we do not understand with notions which we do. Consequently, unless we have a fairly clear conception of what is meant by "hypotheses" and by "verification," we have made no advance. In fact, the definition, at least on the surface, does not look too good, for mathematics is concerned neither with hypotheses nor with verification, and there is a long tradition among natural scientists, beginning with Newton's *Hypotheses non fingo,* running through Mach and Pearson, and ending with contemporary positivists, to the effect that science makes most rapid progress when it abandons the search for hypothetical explanations and confines its attention to mere description and classification.

I

The first step in understanding this definition of science is clarifying the general goal of the scientific enterprise. In the most elementary terms possible, the job of science is to discover facts. Usually this is a simple matter. Many facts impose themselves upon us and we cannot avoid them; living, in fact, is merely a matter of adjusting ourselves to these ever-present facts. But the scientist is instilled with the desire to discover more and more facts. In the attempt to satisfy this need he could, by proceeding very inefficiently, simply look about here and there, waiting, like Mr. Micawber, for something to turn up. But he has been provided by nature with a tool that enables him to do the job much more effectively. Through the activity of his mind he is able to make guesses, controlled by the facts he has already discovered, as to the existence of certain specified facts, in certain specified areas, which he is likely to find if he looks further. Thus by using his mind rather than passively listening to nature he is able to save a great deal of time and effort, since he now knows what to look for and where to look. This directed observation is possible by virtue of his capacity, through imagination and inference, to go beyond the facts already observed and formulate, through the use of symbols and other thought constructions, ideas of objects and processes which may not themselves be capable of observation, but are merely hinted at and suggested by the facts already accumulated. Hence we can describe the job of science more accurately by saying that it is concerned with the construction of a system of ideas that is presumed to portray the realm of facts. At any given stage in science, of course, our knowledge does not fit the facts precisely. On the one hand, since there are many facts that have not yet been discovered, knowledge is always less than the facts; but, on the other hand, since we have anticipated what nature is going to reveal, knowledge is always more than the facts. The final goal of science is to make knowledge fit the facts in all its parts and in all its details.

The method of verified hypotheses can be best understood by considering it from the point of view of its three phases or aspects. One is tempted to speak rather of "stages" than "aspects," and this terminology has a certain advantage. But it suggests a temporal order among the phases of the method, which is somewhat misleading. The important thing is the relations of logical dependence among the phases, not the historical order in which they occur.

The first aspect can be called "getting the facts." In the broad sense, however, it includes not only getting the facts but manipulating, classifying, and correlating them, and perhaps even measuring them as well. The two main processes for getting the data are observation (plus introspection if one wishes to include certain types of psychology) and interpreting reports—both human and instrumental. No one, I should suppose, would call into question the need for resting science ultimately upon observed data; it both begins and ends with things that we see, hear, smell, taste, and touch. This does not mean, of course, that all the entities that are talked about by science are observable, but it does mean that any such as are not directly perceivable must be capable of manifesting themselves indirectly in terms of observable phenomena. Reports are another important device for getting data. What is not commonly recognized is that human reports function in essentially the same way as do instrumental reports. In both cases, we have something that is given through observation (the written or spoken word of another individual, the image on the eyepiece of a microscope), on the basis of which, through a knowledge of the transmitting medium (reliability of the witness, principles of optics), we judge ourselves to be witnessing a natural object (a total eclipse of the sun, the structure of a cell).

Manipulating the data includes all processes—much too numerous even to list—such as combining and isolating, increasing and decreasing in intensity, speeding and slowing, heating, cooling, dissolving, magnetizing, dissecting, which are designed to produce a state of affairs that would not have occurred if we had not put our fingers into nature. These are the so-called experimental techniques, though we shall see in a moment that experimentation functions in a much more definitive way in another phase of science. Here we are concerned primarily with what are commonly called "experiments for discovery" rather than "experiments for proof." These techniques are designed to induce a reluctant nature to yield her secrets; if she will not speak freely we poke and prod her, thus forcing her to respond in unusual ways.

The descriptive processes are many, though for the purposes of this discussion they may be limited to three: classification, correlation, and measurement. Classification involves the activity of grouping similar objects into classes on the basis of common attributes. Correlation, which depends on classification, involves the determination of the frequency with which an object lies in two classes at once, or an object of one class is associated with an object of another class. Measurement is the process of representing the qualities of objects by numbers.

The result of the activities of getting the data, manipulating them, and describing them may be called the "descriptive phase" of science. Many insist that this is all there is to science; a science that has correctly classified and measured all available data has completed its job, and there is nothing to be done except await the discovery of further data, which will then have to be described according to the same pattern. But, whatever may be said for this claim, certainly much of what is commonly included in science is not found here. There are no hypotheses or theories. In the strict sense of the words, neither induction nor deduction has been employed; for the laws, if they are to be accurately descriptive of the data, must be statistical correlations and not universal connections, and no deductive anticipations of future data have been made. There is, in fact, no logical structure evident in the body of symbols constituting a purely descriptive science; each symbol describes its fact, and there is no method by which from the knowledge of one fact we could infer knowledge of another. Consequently explanation is totally absent from such a science; it answers the question How? but does not answer the question Why? A diagram of such a science is given in Figure 1.

The need for including in science something more than pure description arises when the scientist, on close inspection of a descriptive science, notes an important fact. Frequently he discovers that among the symbols constituting such a science one of them, A, implies another, B. This means that if A is true, B must also be true. Of course, B is already known to be true, since it was derived by the direct description of the fact which it represents. But the scientist now knows that if he hadn't happened to discover B, he could have anticipated it from his knowledge of A; thus he could have known of the existence of a fact before he observed it. From this recognition it is but a step to two other very important conclusions. May it not be possible to find another symbol of his scheme, C, which will be found to imply Q, which is not now part of his science but must be included since it is logically demanded by C? And may it not be possible to devise a symbol, K, which is not now part of the science but will imply A, which is already part of the scheme? If the answer to these questions is in the affirmative, he has provided himself with very significant techniques for extending his science into the realm of previously undiscovered facts; he can now anticipate, through an activity of mind based on fact, what nature is likely to reveal in areas that are still unexplored.

This aspect of science may be called the "phase

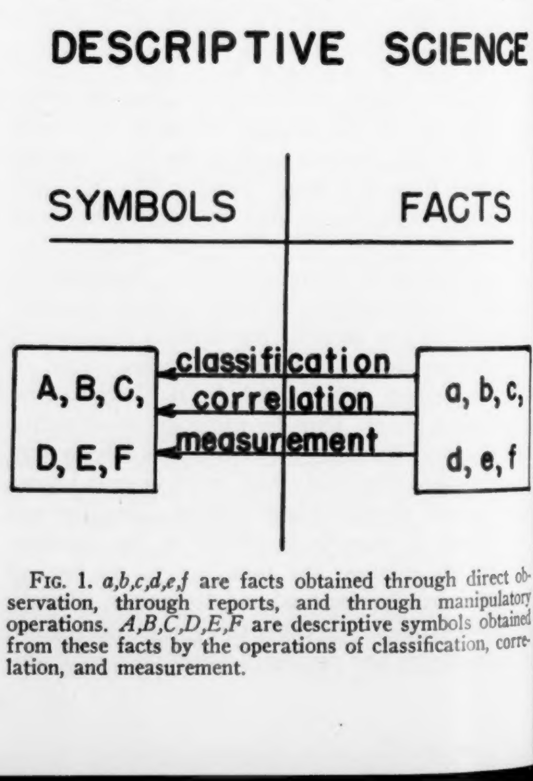


FIG. 1. a,b,c,d,e,f are facts obtained through direct observation, through reports, and through manipulatory operations. A,B,C,D,E,F are descriptive symbols obtained from these facts by the operations of classification, correlation, and measurement.

of discovery." In actual scientific procedure deductive expansion of a scheme—i.e., expansion by finding further symbols which are implied by symbols in the scheme—is comparatively rare, and the cases in which it occurs are usually trivial. But expansion through induction—i.e., by finding symbols not in the system which imply symbols which are in the system—is a highly significant method. It is, in fact, precisely what is meant by the discovery of hypotheses. The nature of this movement has not yielded to logical analysis. We call it variously "insight," "intuition," "hunch," "illumination"—attempting by all these words to cover the fact that we do not know precisely how it occurs. Deduction is well understood; we know how it operates and we can set up the rules for its validity. But induction is still essentially a mystery. All that we can say about it can be exhausted in a few propositions. It is essential to science. It does occur on numerous occasions. It produces most significant results when preceded by a long and persistent study of facts. Ability to make inductions is distributed very unequally among men.

The most significant defect of induction, however, is that it never gives us truth, but only possibility or, at best, probability. This can be seen from the nature of the implicative relation. If K implies A, then if K is true A must be true. But if A is true we cannot infer from this to the truth of K. K might be false and still imply a true proposition. Since the relation of implication is more commonly expressed in terms of explanation, we can state the same fact by saying that whereas K explains A something other than K might explain A equally well. To be sure, when K occurs to a scientist through an act of illumination or a flash of insight, it usually carries with it a strong feeling of conviction. He feels at the moment that it *must* be true. But later experience usually shows him to have been mistaken, as he quickly learns if he tries to play the races on similar hunches, and as he would readily admit if historians had reported the scientific failures as faithfully as they have preserved the records of scientific successes. The plain fact is that ideas obtained through this act of inspiration, however plausible they may appear at the time, are nothing more than well-founded guesses, and they must be substantiated further before they can be included among the established truths of science. This testing requires the examination of a further phase of science, the phase of verification. Before passing to such considerations, however, mention must be made of another feature of a science that is undergoing the transition from the descriptive to the explanatory stage.

In the search for implicative relations among descriptive symbols the scientist readily sees that these relations do not hold among fuzzy concepts or highly complicated propositions. If, for example, he were to determine the sum of the angles of a triangle by actual measurement, he would find this very rarely to be exactly 180°; in the great majority of cases it would be greater or less than this amount and to varying degrees. Consequently, if geometry were a descriptive science, he would have to express his results statistically, stating, with regard to any class of triangles, how many had the sum equal to 180°, how many were less than this by one second, how many were greater by one second, how many less by two seconds, and so on. It would be extremely difficult, if not impossible, to construct a theory of the triangle in terms of which this could be understood. But it is readily seen that these values fluctuate around 180°, and it requires no great stretch of the imagination to suppose that if the triangles were perfectly drawn the sum would always exactly equal this amount. A simple substitution is then made that immediately brings about this result; the meaning of the word "triangle" is changed to mean "perfect triangle" rather than "actual triangle." The law of triangles then becomes exactly true of perfect triangles, though only approximately true of actual triangles, and can then be explained in terms of the simple definitions and postulates we learned in our high-school geometry.

The frequency with which such notions occur in science, and their importance for a general theory of science, are not generally recognized. Geometry, in the strict sense of the word, is made up wholly of concepts of this kind, with consequences which we shall see later. Physics would find it hard to dispense with perfect gases, ideal levers, frictionless motion, and the like. In the social sciences frequent use is made of such fictions as the completely isolated individual, the ideal State, and the purely economic man. What should be clearly understood in connection with such notions as this is that a science in which they occur has, to this extent, lost its descriptive value. In this elaborating and refining process, which Eddington calls the method of "just like this only more so," we attempt to get away from the complexities and crudities of sense objects in order to replace them by simpler and more precise counterparts. But to the extent to which they are simpler and more precise they are no longer counterparts.

The world does not contain perfect levers, ideal gases, economic men, and utopias; when we build science on such notions, therefore, we are no longer talking about the world in which we live. Many who praise the exactness and precision of science fail to realize that only through the use of such fictions and idealizations does science have its mathematical rigor. Applied science fits the world better, but it lacks the neatness and logical structure of idealized science; idealized science has the required coherence, but it loses to a great extent its descriptive value. Einstein has expressed this very well in a statement that is often quoted: "As far as the laws of mathematics refer to reality, they are not certain; and as far as they are certain, they do not refer to reality."

II

Let us now turn to a consideration of the next phase of science—verification. This may be broken up into two subphases. The first involves making predictions on the basis of the assumed hypotheses. This is deductive in character; it begins not with the descriptive symbols, however, but with the hypotheses. The scientist simply asks himself what would have to be true in nature *if* his hypothesis were correct. Such predictions always have the *if . . . then . . .* form, where what follows the *if* is the hypothesis, and what follows the *then* is the anticipated observations, either experimental or nonexperimental. The second of the two phases involves the checking activity. The predicted consequences are compared with the actual facts as disclosed through observation; and the hypothesis is rendered more probable or rejected according as these agree or disagree. In this phase the techniques are the same as those in the descriptive phase—getting and manipulating the data, and classifying, correlating, and measuring them. The direction of the activities is reversed, however: there we were given the data and were concerned with devising symbols; here we are given the symbols and are attempting to verify them in the data. It is in this stage, rather than in the descriptive stage, that experimentation plays its distinctive role.

A science that exhibits all three phases may be called an "explanatory science." This is what is commonly meant by the term when it is employed in ordinary discourse. In a sense, of course, an explanatory science includes a descriptive science, since the former was obtained from the latter by extension through the use of hypotheses and theories. But, as has already been pointed out, this is not quite the case. An explanatory science, by virtue of the use of abstractive and idealizing activities, has lost some of its direct descriptive value. It has lost contact with reality to the extent to which it has achieved a certain logical structure. Whether this involves a net gain for the science itself is debatable; thus we cannot dogmatically assert that an explanatory science is "better" than a descriptive one. But certainly in our recognition of the possibility of such a thing as an explanatory science, we have advanced in our *conception* of science; we now see more clearly what "science"

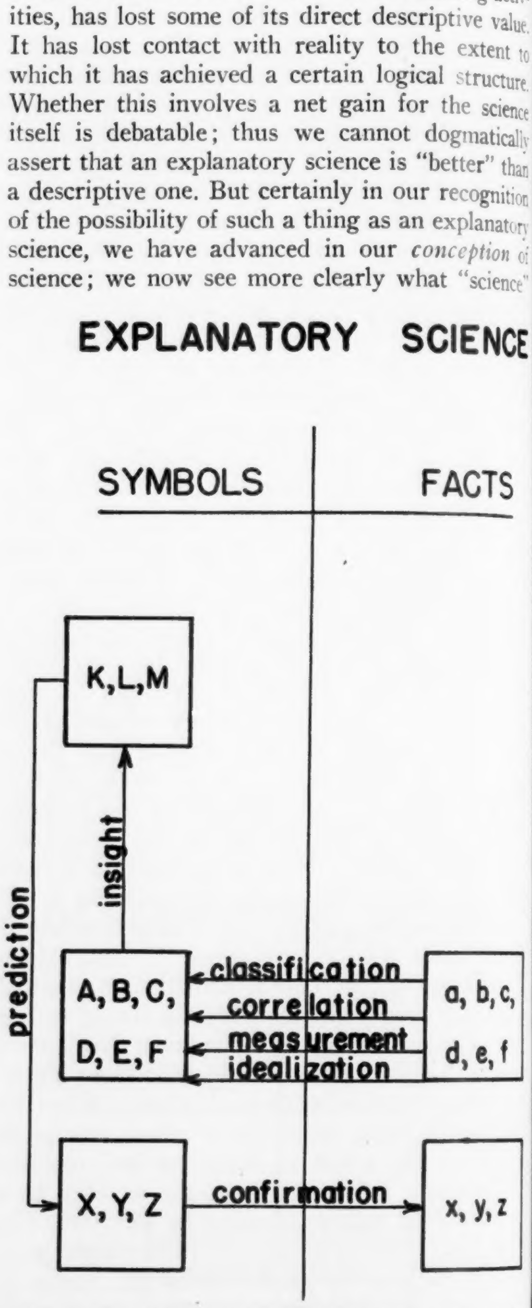


FIG. 2. *a,b,c,d,e,f* are facts obtained through direct observation, through reports, and through manipulatory operations. *A,B,C,D,E,F* are descriptive symbols obtained from these facts by the operations of classification, correlation, measurement, and idealization. *K,L,M* are hypotheses or theories obtained from the descriptive symbols through insight (induction). *X,Y,Z* are the predicted consequences of the hypotheses, derived from them by deduction. *x,y,z* are the newly discovered facts which confirm these predicted consequences.

means. A diagram of explanatory science is given in Figure 2.

But we are now in a position to realize that the picture is still incomplete. In fairness to mathematics and certain parts of physics, further elaboration of the notion of science is required.

A candid examination of an explanatory science, even one that is highly developed, discloses some significant inadequacies. Rarely is it true that the total body of descriptive symbols can be completely explained in terms of the hypotheses. There are almost certain to be some loose ends, some brute facts, some statements that are descriptively true but cannot be fitted into the scheme. In some cases we may succeed in integrating small groups of the descriptive statements by devising theories that explain them. But these remain islands of order in a sea of disorder. Only rarely can we find a more comprehensive theory that integrates the subgroups with one another just as the simpler theory integrates the statements within the subgroup. All these inadequacies lead us to speculate concerning an ideal state of science in which the logical organization would be perfect and complete. This would presumably be one in which all descriptive statements would be capable of being derived by pure reason from a single theory, this theory itself being so constituted as to be as simple as possible and to involve no internal contradictions. Such an ideal would be achieved in physics, for example, if from a theory of the electron, or some other elementary particle, we could deduce all the phenomena of physics—dynamical, acoustical, electrical, optical, and perhaps even chemical as well.

If, however, we step outside the field of the so-called natural sciences and look about for such a logically complete science, we find one immediately at hand. Geometry (and, in fact, most of mathematics) is precisely such a science. In order to see that this is the case we have only to introduce a substitute terminology. Instead of hypotheses and theories we must speak of axioms, definitions, and postulates, and instead of laws and descriptive statements we must speak of theorems and corollaries. The logical structure is complete, for, at least in a perfect scheme of this type, all theorems and corollaries can be proved in terms of the axioms, definitions, and postulates. But when we consider the abstract character of such a scheme as this, and when we recognize the existence of non-Euclidean geometries, we readily see that the gain in logical cogency has been achieved at the sacrifice of descriptive accuracy. The idealizing activities, which were mentioned earlier, have so dominated the science that it can no longer be said to be about the world at all. The existence of such a science as this shows that the human mind has the capacity for taking at random any group of ideas, actual or fanciful, combining them and deriving their consequences by pure reasoning, and thus constructing a system of underived and derived notions which is internally perfectly consistent, which obeys the rules of logic throughout, but which may convey no information whatever about the world in which we live. Such a science may be called "rational" or "autonomous" and may be represented diagrammatically as in Figure 3.

III

If our analysis of science is correct, each of the sciences should fall roughly into one of these three

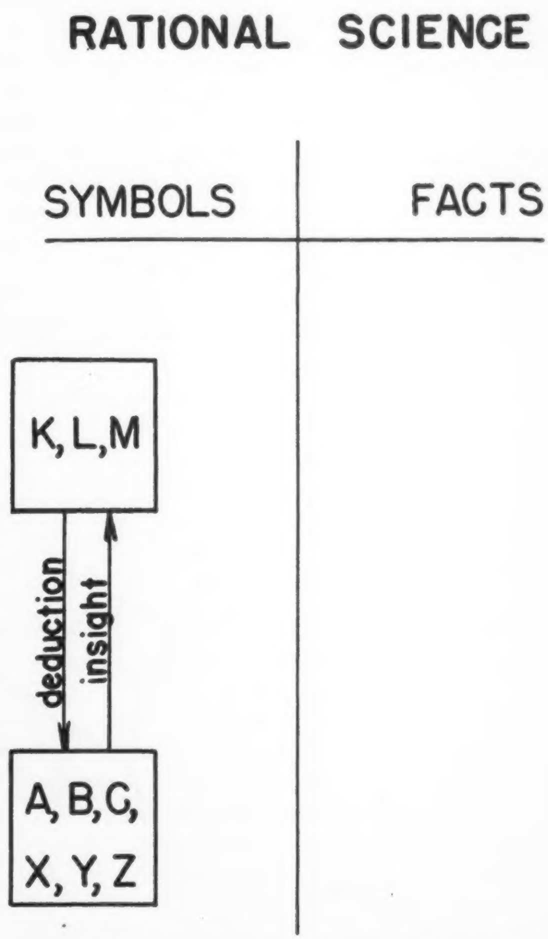


Fig. 3. *K,L,M* are the underived ideas (axioms, postulates, and undefined terms). The axioms and postulates are assumed to be true, and the undefined terms are assumed to be understood. *A,B,C,X,Y,Z* are the theorems. They are proved to be true by deduction through pure reason from the underived ideas.

classes—descriptive, explanatory, or autonomous. Just where it is located will depend on a number of factors—who is doing the classifying, what part of the science is being emphasized, how certain words in the science are to be defined (for example, does "line" mean "something that can be drawn on paper with a pencil" or "length without breadth and thickness"?), the historical stage in which the science is being considered, and so on. Few, however, would deny that autonomous sciences are today well represented by mathematics, rational mechanics, and perhaps other limited areas in physics; explanatory sciences by the rest of the physical sciences and biology; descriptive sciences by the social sciences and psychology, with many, perhaps, preferring to place biology in this class rather than in the class of explanatory sciences. No doubt there is also a *rough* correlation between the development from description through explanation to autonomy, and the actual history of any science. If this correlation were perfect, the autonomous sciences would all be the oldest, and the descriptive sciences the youngest. The fact that geometry was already well developed as a deductive science in the days of the Greeks, and that psychology, which began with the Greeks, is still essentially in its descriptive phase today argues against identifying the logical and the historical developments. No doubt something more than *time* is required for a science to pass from description to autonomy; certainly the character of the subject matter plays a definitive role. It does appear, however, if the above analysis is correct, that a descriptive science remains in this stage only with difficulty. There is, first, the irresistible desire on the part of the human mind to ask the question Why? and to attempt to answer it by engaging in flights of imagination. Second, there is the recognition of the heuristic value of hypotheses in the discovery of new data. To this extent the positivist is wrong in insisting that descriptive science represents science at its maturity. Furthermore, once the value of logical structure has been appreciated fully, there is an unrestrainable desire to idealize the subject matter of the science, break its connections with the world, and set it up as a deductive scheme. To this extent the natural scientist should not look with too much scorn on the purely formal character of mathematics.

The type of science that one prefers is, I believe, largely a matter of temperament. The positivist insists on being close to the facts and avoiding speculative notions; the advocate of explanatory science wants to get behind and beneath things to see how they run; the formalist is unhappy in this higgledy-piggledy world and much prefers the neatness of abstract systems.

ENLIGHTENED AFRICA

LOUISA CLARK WILLIAMS

Mrs. Williams (M.A., Chicago) has taught at the University of Wisconsin and studied in Europe as a Marquand Fellow. Since her marriage to Dr. Williams, for the past thirty-one years an entomologist of the Hawaiian Sugar Planters' Association, she has accompanied him on expeditions to New Caldeonia and to British East Africa (1947–48). Mrs. Williams is a contributor to various periodicals.

A United States Navy request mission sent us to British East Africa to look for enemies of the giant African snail *Achatina* and to ship suitable ones to the Palau Islands in the Pacific, where these voracious vegetarians were causing serious damage to the local food supply. The big snails swarm en masse over the roads, and even whole hillsides, of these tiny islands, so that cars crunch and skid queerly over them, and the brown slopes seem to be crawling.

While carrying out this mission, Dr. Williams and I "discovered" such an enlightened series of vigorous, well-developed agricultural research organizations in the heart of "Darkest Africa" that my idea, at least, of Africa was revolutionized. This "discovery" would surely surprise many another American who also knows equatorial Africa only from museums, zoos, books on anthropology, and the tales of the big-game safaris. For me, it rivaled in interest the successful hunt for snail enemies.

Many species of *Achatina* have been identified, and it is well established that this snail is indigenous to Africa. The shell is cone-shaped and gray, streaked with brown. About two years after it hatches from its egg (the size of a lentil), the shell grows to be, in most species, five to seven inches long. Some in West Africa grow to be even larger.

The most widely traveled species is *Achatina fulica*. It is native to the lowlands of tropical East Africa, including Zanzibar Island, 25 miles off the coast of Tanganyika. The record of its travels begins on the great island of Mauritius, still farther out in the Indian Ocean. During the past hundred years or more, *A. fulica* has been carried, in general deliberately, by human beings as food for themselves and their poultry, to most of the tropical lands of the Indian and Pacific Oceans.

A record dated about 1857 speaks of an enthusiastic malacologist who took some to Calcutta for purposes of dissection. In 1900 great damage in Ceylon was reported. Similar reports came from Malaya in 1923, Singapore in 1928, and Hawaii in 1938. The Japanese spread *Achatina fulica* throughout their Mandated Islands in Micronesia. Now these hungry snails are reported also from Java, Borneo, Amoy (China), the Philippines, Formosa, and (for a short time) California; a giant snail reported to be *Achatina panthera* is causing great alarm in New Guinea now.

In each new, lush, tropical region this snail has increased rapidly, far from its natural enemies. Imported for food, it is soon eating up more food—growing young food plants—than it could ever supply, even to those with a taste for snails. In 1936 in the Hawaiian Islands, for example, a local Japanese had twelve *A. fulica* brought in through the mail, thus escaping the vigilant agricultural quarantine officers. He was busily raising and eating the snails in his own house until 1938. Then the Territorial Board of Agriculture and Forestry heard about them by accident when another Japanese innocently asked the Board how to raise the big snails, a few of which had been given him by the original importer. Quarantine officers immediately went to the house of the busy snail raiser and there found and destroyed 1,387 *A. fulica* of various sizes, as well as a large quantity of eggs and newly hatched young. Even so, some snails must have escaped, for they soon showed themselves happily established in gardens of the neighborhood, eating, multiplying, and growing fast.

On another island of the Hawaiian group, a Japanese woman imported some *A. fulica* from Formosa. Before they could be discovered and killed, some of these also escaped into the gardens roundabout and went to work. Today, in Hawaii's year-round warm, rainy weather, these big snails have become a serious threat to all vegetable and flower growers. They have been kept down to a threat only by the constant watchfulness of the Board of Agriculture and Forestry, the alarmed reports of their presence, and quick action in destroying all that are reported. Large sums of the taxpayers' money have had to be spent in poisoning these pests. One call for help not long

Two views of *Achatina.*

ago concerned only two *Achatina* that had been seen in a garden. Poison was promptly spread by the plant inspectors, and the next morning more than 200 dead *Achatina* were counted in that garden. (The snails come out mainly at night to feed, mate, and lay eggs.)

We can better understand the alarm of vegetable and flower growers over only two of these snails when we realize that just one of them, in a single night, could destroy the results of weeks of hard, devoted work and thus much of the season's income, especially when the plants are young. Poisoning, however, is an expensive and never-ending procedure. It is a losing battle against insect or snail pest. For many years now, the entomologists of Hawaii, concerned with the great sugar and pineapple industries, as well as with the routine food crops, have been using biological control methods to deal with each newly arrived pest, often with spectacular results. When, therefore, the Navy, from its office of Island Governments in Washington, turned to the Pacific Science Board of the National Research Council for help, the entomologists in Hawaii were among the first to be consulted.

Dr. Williams, a veteran of more than thirty years in explorations for this method of pest control by the Experiment Station of the Hawaiian Sugar Planters' Association, was available and was asked to undertake a Navy mission to Africa to discover the enemies there that keep down the numbers of the giant snail so that it never becomes a pest where it is indigenous.

ON THE ISLE OF CLOVES

Dr. Williams and I arrived in Mombasa early in December 1947 and left late in June 1948. For three months of that time, during the dry season when snails and their enemies are estivating, we traveled through Kenya, Tanganyika, and Uganda, consulting the local scientists about *Achatina* and making direct observations. Both agricultural scientists and laymen there knew the monster African mollusk, but only as just another curious wild creature. They were astonished and interested to hear of its wide distribution and its depredations. Dr. E. B. Worthington, Scientific Secretary, Office of the East Africa High Commission—the dynamo at the heart of all the far-flung research of many kinds—in contrast, spoke at once of the need to determine and import an effective enemy of *Achatina* into Singapore and Malaya.

We spent a month on Zanzibar, a low, almost flat, coral island—an Arabian Nights sort of world under a hereditary Arab ruler, the Sultan. The British Protectorate rather encourages the dreamlike quality of life on Zanzibar, even while it maintains order and hygienic conditions and tries to promote better methods of agriculture. It was there that we visited our first agricultural research stations, in fact. (We went there chiefly to ship out *Scolia* wasps, which prey on the coconut beetle *Oryctes,* which is reducing the coconut crop in Micronesia.)

The principal industry of Zanzibar is cloves. There, in a laboratory that was once the home of David Livingstone, a group of five or six trained British scientists of the Clove Research Scheme is working to save the industry that supplies most of the world's cloves—to season your baked ham, to give candies a "vanilla" flavor, and to provide oil of cloves for many kinds of medicine. Dr. F. J. Nutman, the Director, says in a letter:

> As you know, the main wealth of Zanzibar lies in the clove industry, and it is very difficult to think of any other crop which could be an adequate substitute. Furthermore, the locals [descendants of Arabs who started the great

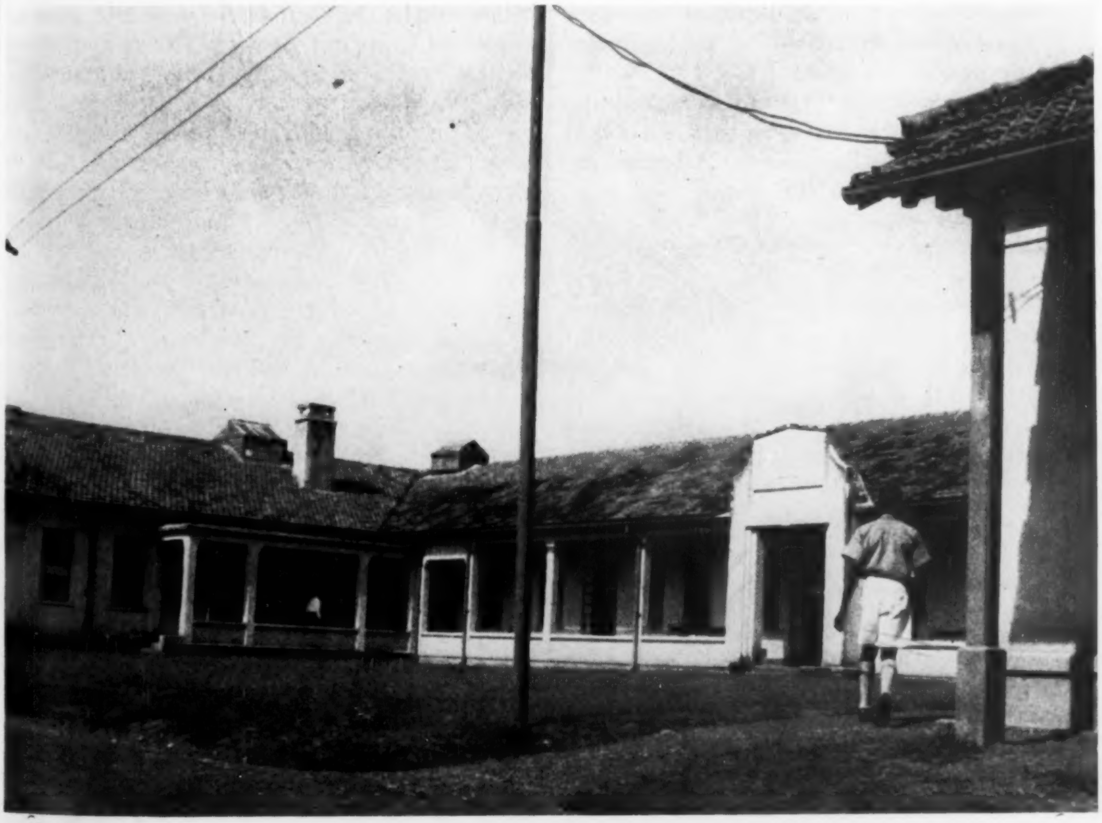
clove plantations around the year 1800] have a kind of psychological attachment to the tree, although I believe this is wearing a bit thin these days. The disease known as Sudden Death has been present for many years—so far as one can tell. But it is only comparatively recently that its seriousness has been realized. . . .

During 1946–7 I studied the disease and drew up a programme of work. This was very thoroughly examined during 1947 by leading authorities in England, and I was able to pay a visit to the States where I received an uncommon amount of help and kindness . . . The British taxpayer is providing most of the money for the next few years.

When "Sudden Death" strikes, a great clove tree is one day apparently as vigorous as ever, and three days later a stark, completely dead skeleton. The initial approach to the problem was that the disease might be caused by a virus carried by scale insects fostered by ants. With this in mind Dr. Nutman was studying what had been done on the diseases of elm and citrus trees, which appeared to be similar.

For diversified agricultural research, Zanzibar has the experimental farm and research station at Kizimbani, about 10 miles from the town of Zanzibar. On the way to Kizimbani, we drove through the narrow, crooked streets of the town between stone walls that crowded closely on each side, and soon came to good country roads. These took us through clove plantations, where many great trees had fallen victim to "Sudden Death." Nevertheless, in 1947 the products of the clove tree were responsible for 58.6 percent of the Protectorate's total exports. There were many coconut plantations also, for the coconut palm is responsible for another 33.18 percent of exports. The Kizimbani Agricultural Research Station is on a farm of some 500 acres in the middle of a group of plantations totaling 3,500 acres. The agriculturist and his family live comfortably in a cool stone house of European style. There, of course, we enjoyed the gracious English custom of afternoon tea on the veranda overlooking a wide, immaculately groomed lawn made colorful by old trees supporting flaming bougainvillaea. In contrast to this luxury, the farm buildings and farm work and equipment are kept only a step or two ahead of the local Arab and African practices in order to be of the most use to the most people of the Protectorate.

An important new development is the selection of a crop alternate to the ailing clove industry.



Main office and laboratory buildings of the Kawanda Agricultural Research Station in Uganda.

Barns at Kawanda Agricultural Research Station, Uganda.

Cacao, the source of chocolate, has been chosen. Several old cacao trees of the superior Crillo type have been found still growing on Zanzibar after fifty years of almost complete neglect, as well as occasional fires. These trees, or others of this stock, should supply hardy plants for the new plantations. If not necessary now, this new industry is considered at least an essential insurance policy. Cacao products should be salable under almost any market conditions.

Thus Zanzibar showed us in microcosm the pattern of agricultural research that we found everywhere in British East Africa. A special research organization served the major local crop, and general agricultural research and education dealt with the diversified products—all at government expense. This is the pattern of agricultural development with which we were familiar in Hawaii, although there the two major agricultural industries, sugar and pineapples, support their research privately. Unique for Zanzibar is the fact that, among the various sections in the Department of Agriculture, there is the Plantation Section, which looks after the extensive properties under the control of His Highness the Sultan's government.

RESEARCH IN UGANDA

One of the older and better-developed of the organizations for diversified research in British East Africa is at Kawanda, near Kampala in Uganda. How completely different from Zanzibar is that cool, green, hilly country, four thousand feet above sea level!

We were not surprised to find such a strong group of agricultural scientists where British and other missionary and commercial work has been going on longer than elsewhere in East Africa. We read that "Buganda Province of Uganda is one of the most productive areas in all Africa, being blessed with good rainfall and fertile soils" (Notes on Agriculture in Buganda and on Kawanda Agricultural Research Stations. July 1946. Mimeograph). In Uganda, we were told, there are almost no European farmers. This is quite unlike Kenya, where most of the agricultural work, mainly in coffee and sisal, is on large plantations owned and managed by Europeans using African labor. The only large holdings of any kind in Uganda are the three great sugar plantations, of which two are owned by East Indians and one by an Englishman. Very significant is the fact that cotton, the chief and most profitable crop of Uganda, is all raised by Africans on their small holdings. Here, too, the African farmers raise the other commercial crops, tea, coffee, and bananas.

The entomologist at Kawanda, Dr. W. V. Harris, told us that in 1937 various somewhat independent research departments were combined and established on an old rubber plantation of about 399 acres that had been bought by the government in 1934. Later, 750 acres more were bought for a seed farm. Several of these separate departments—such as the entomology department, which was started in 1908—had been at work for many years.

Today, to house the large British research staff and their families, an attractive village of roomy brick houses and trim gardens has grown up along the crest of the wide-spreading ridge that constitutes the farm, and appropriate cottages for the many trained African assistants are not far away. Extensive modern laboratories and machinery

equip the special skills of this varied staff. The farm buildings, however, as on Zanzibar, are of the local African type, with thatched roofs over mud and wattle walls. And the dairy cattle are only improved strains of the local zebu stock.

The type of basic research carried on at Kawanda is suggested in the Notes:

> The system of management has been based upon the use of a grass ley for the maintenance of fertility. As a preliminary for initial cropping most of the cultivable area was planted up with elephant grass after opening in order to restore soil structure. This was particularly important on the land previously under rubber where . . . the soil had become hard and compacted. Apart from the establishment of coffee and other permanent crops there was little development of the farm until 1940. . . .
>
> A system of strip cropping with grass leys is followed on all blocks cropped with annual crops. The width of strip varies from 20 to 50 yards and rotations have been designed to obtain information on the Cropping: Rest ratio and the management of the land during resting periods. The cropping periods are from three to four years combined with grass ley of from two to four years. The grass leys used are elephant grass, which is either left undisturbed until brought back into cultivation or grazed in the final year, and selected short grasses on which grazing trials are conducted. Farmyard manure is applied in the first year of the grass ley on certain blocks. The cropping rotations are of an indefinite nature and permit the widest latitude of cropping within a simple framework of legume, straw and root crops associated with cotton.

Cotton being Uganda's principal crop, the research station naturally devotes much effort to methods of its cultivation and to the distribution of improved cottonseed. By-products of the seed, such as oil and seedcake for stock, also receive attention. A cotton gin at the research station handles, and thus can control the selection of, all this cottonseed.

Coffee, of the *Robusta* variety, is important and receives considerable attention from the scientists as to improved varieties, pest control, and cultivation. A well-known factor in improving the flavor, it seems, is not so much whether the coffee is grown in the shade as it is the care with which the last of the pulp around the bean is fermented off. Coffee brings such a good price these days that even the various coffee research projects make a good profit—"for the King."

Still other crops studied—though they are as yet less important commercially—are tea, hemp, annis, peanuts, cinchona, and bananas. The sugar growers' problems also receive consideration.

To spread improved methods of farming, breeds

On beautiful Lake Bunyonyi among the green hills of western Uganda.

of cattle, and varieties of seed, the Protectorate of Uganda is divided into districts, each with a European agriculturist and several African assistants, who make the most direct contacts. At Bukalasa—an older agricultural station—agricultural instructors are trained, and courses are given for chiefs, cultivators, and schoolmasters. A temporary center for training ex-soldiers has also been opened there. Makerere College in Kampala, with nearly three hundred students and a well-developed curriculum, is another center for training native African agriculturists. It has especially strong departments of biology and agriculture. Its students in this latter field spend their last school year (six months in length) in training at the Kawanda Station.

There is evidence that this research and education are taking hold among the small farmers of Uganda in other lines than the production of cotton. For example, proper milk production is becoming popular; and pig raising has increased so much that a bacon factory has been started.

KENYA AND TANGANYIKA

In Tanganyika, lonely, beautiful Kilimanjaro has many coffee plantations on its far-spreading lower slopes. The highest mountain in all Africa (over 19,000 feet), it wears a cap of perpetual snow. Well-watered forests extend below this. Together, the snow and the forests cool and water the country roundabout, making ideal conditions for coffeegrowing. The Tanganyika Coffee Research Station, near Moshi, serves this region.

Mount Kenya, part of a fairly long range, also has a snow-clad peak and a belt of rainy forests to cool and water the many plantations of *Arabica* coffee on its broad slopes. Coffee is grown extensively elsewhere in Kenya Colony. Naturally, then, we found a coffee research station in Nairobi, capital of the Colony. It was located in part of the Scott Agricultural Laboratories. The work of this early establishment is now being transferred to a larger development on a farm of 350 acres some twenty miles from Nairobi, the Jacaranda Coffee Research Station, where everything is still very new. Their scientists, however, have had long experience, and the results of their work, with themselves as the extension agents as well as the research scientists, are in great demand wherever coffee is grown in Kenya.

The most conspicuous achievement of the entomologists, R. H. Le Pelley and A. R. Melville, is the control of a certain very destructive mealy bug on coffee, *Pseudococcus kenyae*. First noticed as a serious pest in 1923, this mealy bug, like many

W. V. Harri. beside termite skyscraper, details of which he has been studying. Many termite cities are taller than this one. The soil from these mounds packs into an excellent surface for tennis courts or the floors of native huts.

other creatures in Africa, was new to the scientists. In search of an insect to destroy it, Dr. Le Pelley traveled for a number of years in all parts of the world. He sent back to Nairobi, from four continents and several large tropical islands, enemies of mealy bugs. But nothing happened in the coffee plantations of Kenya. Then, in 1938, the two entomologists began looking around in Africa. Perhaps, they began to think, this mealy bug was a strictly local insect. Perhaps, therefore, its enemies would be strictly local, too. They were right. Mr. Melville discovered, practically next door in Uganda, a "pocket" of exactly the same kind of mealy bug and enough of its enemies to make a start in the battle against it. These enemies, imported into Kenya's coffee plantations, soon had the mealy bug under control. The most effective of several enemies imported was *Anagyrus* near *kivuensis*. Since then the chief work of that part of the Scott Laboratories has been to breed these beneficial insects and liberate them in coffee plantations.

A whole delightful week as the house guests of Dr. D. W. Duthie, the Acting Director of the East African Agricultural Research Institute at Amani, gave us a thorough view of its plant and some of its work. Amani is one of the central research institutions serving all of British East Africa. Though its work is mainly in agriculture, it is equipped to turn to other fields when necessary—such as during World War II.

The Germans gave expression to their love of

the picturesque by planting a vast horticultural garden in the midst of virgin jungle on the steep mountainsides. When the British took over Tanganyika after the first world war, they eventually made many improvements. Now fifteen comfortable dwellings and ten work buildings—laboratories, greenhouses, a library, and an administration building—perch on the various ridges, each commanding a magnificent view. The extensive grounds are beautifully arranged and always well groomed. Trim hedges separate the lawns, rose arbors, flower beds, and pools from the tremendous jungle that encroaches on three sides. Two-hundred-foot treetops tower over this rather prim bit of civilization, and monkeys swing on loops of great vines.

At its largest, Amani had a staff of sixteen European scientists. The number is fewer now, mainly because the excellent and experienced men of Amani are so much in demand for important posts elsewhere. For example, Dr. H. H. Storey, F. R. S., is now in London as Secretary to the Colonial Agricultural Research Committee. The most recently published report of research there covers the war years 1942–45. Much of the normal agricultural research was in abeyance, but those of the staff who remained carried out wartime assignments such as the following:

Camphor. As a result of successful pilot-plant experiments, a camphor factory for the exploitation of *Cinnamomum camphora* was erected at Lushoto by the Amani staff in 1942. The Tanganyika Railways designed and supplied most of the essential machinery. The factory was closed in July 1943, the supplies of camphor wood having been exhausted.

Ceramics. Following the demand for pottery utensils and containers, experiments were undertaken in 1942 by J. Glover, assisted by Mrs. L. Goldstucker, with a view to producing these from local materials. Preliminary work showed that satisfactory unglazed ware could be made from local clays and that African labor could be taught to use the potter's wheel. Prolonged investigation in the laboratory was necessary before suitable glazes were found to fit these local clays and those submitted by pottery workers in Kenya.

Chenopodium oil. This was produced on a laboratory scale by J. Glover from *Chenopodium ambrosioides* var. *anthelminticum* grown at Amani. The sample complied with the United States Pharmacopoeia standards but not with those of the British Pharmacopoeia.

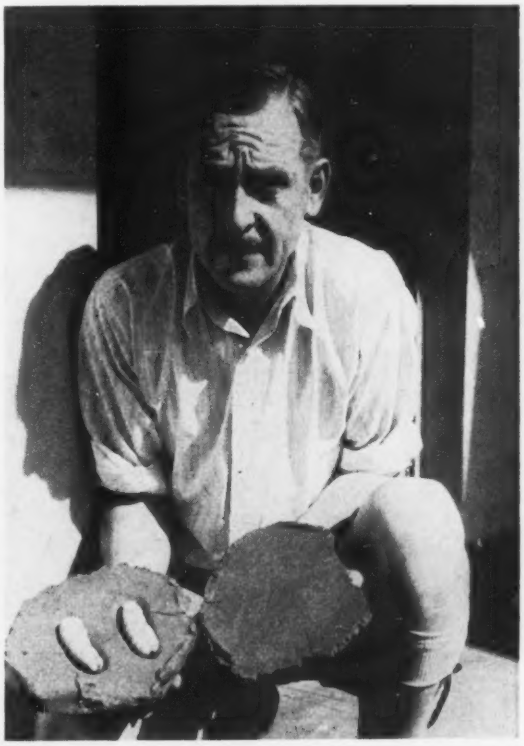
Creosote. R. R. Worsley experimented with the production of creosote oil from producer-gas tar, previously considered a waste product. He produced a disinfectant of the Jayes' type, the formula for which was supplied to a Nairobi firm for manufacture and supply to His Majesty's Forces. Medicinal creosote was also prepared. Crude creosote from local wood tar was shown by J. Glover to give satisfactory protection to wood against two common species of termites.

Dehydrated castor oil. A lengthy investigation was undertaken by J. Glover to discover a substitute for linseed oil and similar drying oils used in paint manufacture. A method was evolved for preparing dehydrated castor oil, using East African kaolin as a catalyst. It was shown that a range of satisfactory drying oils could be prepared by this method, details of which were published in *Technical Pamphlet No. 3* of the East African Industries Technical Advisory Committee.

Petrol from oil seeds. R. R. Worsley spent a considerable amount of his time during 1942 in perfecting a process for the manufacture of high-quality petrol from oil seeds. The process was patented in the United Kingdom.

Glycerin, fatty acids, and stearine. R. R. Worsley experimented with a specially constructed autoclave and demonstrated that coconut and cottonseed oil can be split satisfactorily, on a pilot-plant scale, to produce good quality crude glycerin and fatty acids suitable for soapmaking. The stearine obtained from the splitting of cottonseed oil made good candles. The hydrogenation of cottonseed oil free fatty acids, prepared by the autoclave process, was successfully carried out on a laboratory scale, and soap made from the hydrogenated product; this soap was hard enough for normal household use.

In the course of time Amani has proved to be too picturesquely—and not conveniently enough—placed for such an important government service. Arrangements had been nearly completed when



Dr. Harris, entomologist at Kawanda Agricultural Research Station, shows two vast termite queens in the kind of mud cells in which they live, each pouring out eggs for her own skyscraper termite city. The termite king is a midget by comparison, and the workers and fighters are the size of large ants.

we were there whereby the Amani staff will be absorbed into a wider group, the East Africa Agricultural and Forestry Research Organization. Amani will be continued as a substation.

OTHER RESEARCH

The Rockefeller Foundation has several research groups in Africa working on the tropical diseases malaria and yellow fever. For years the British government has been studying the devastating tsetse fly. We did not happen to see any of these flies, but occasionally our car was required to stop and be searched for them, mainly under the chassis. Once in Uganda, it had to be driven into a snug shed and fumigated.

The Yellow Fever Research Institute has its main laboratories at Entebbe in Uganda on Lake Victoria. A. J. Haddow is the entomologist in charge. Two hundred miles away, east of the "Mountains of the Moon," or the Ruwenzories, where the Belgian Congo begins, we found the other part of this Institute of the Rockefeller Foundation. We came upon it at Bundibugyo in the Bwamba Forest, where the Africans are extremely primitive. As we cruised through the village, we found no indication of the laboratories, except a somewhat tidier wall of elephant grass surrounding a compound, rather larger than most and having unusually snug and thick thatch on its houses. Inside the houses, however, nothing was primitive. Dr. Lumson, the entomologist on duty, showed us excellent laboratories.

Local monkeys and other wild creatures carry the "jungle yellow fever," but are immune to it themselves, thus serving as vectors. (Two pockets of "jungle yellow fever"—in the Belgian Congo and the Amazon River jungles—continue to harbor this disease.) Monkeys from India not being immune, they are tethered on long platforms in the treetops of the Bwamba Forest, where they keep company with the yellow-fever mosquitoes and the local monkeys. After becoming infected, they are brought to the laboratory to live comfortably while blood samples are studied and other observations made.

The East Africa Agricultural Research Station at Amani. Administration Building in background, with a hill slope planted with experimental tea.

MISSION ACCOMPLISHED

Returning to the coast, Dr. Williams worked from mid-March to late June in the Mombasa region inland from Diani Beach. Here the snails were abundant—the exception rather than the rule in the part of Africa we saw, for the big snails generally were scarce. By great good luck, a well-kept little seaside hotel was near by, allowing us to rough it quite smoothly. The long rainy season, due in March, had scarcely begun in earnest by the end of May. Thus neither the snails nor their enemies were at their full activity. The snail enemies Dr. Williams had expected to study were carabid (*Tefflus*) and drilid beetles. During December in Mombasa, he had found drilid moult skins inside empty *Achatina* shells, suggesting the identity of the killer. He had also found a live drilid larva and an adult carabid in the act of eating a live *Achatina*. Each had its head so deeply pushed into the snail shell and was so absorbed in eating that no amount of handling disturbed it.

The unexpected snail enemies at Diani Beach —the carnivorous snails *Gonaxis* and *Eduntulina* —were more conveniently studied in the lightly rainy weather. Dr. Williams' investigations, in the laboratory and afield, convinced him that these are largely responsible for keeping down the numbers of *Achatina* in Africa—at least in the districts he studied. Dr. Joseph C. Bequaert, of the Museum of Comparative Zoology at Harvard, the specialist in land mollusks of Africa who was consultant to this Navy mission, supports this conclusion, arrived at independently.

ACKNOWLEDGMENTS

Since any significant piece of work is always the product of the combined efforts and skills of many and varied persons, it seems fitting to make suitable acknowledgments.

To the staff, and achievements, and facilities of the Experiment Station, Hawaiian Sugar Planters' Association in Honolulu, for their pioneer and still leading work in biological control of tropical insect pests.

To the United States Navy for its intelligent, farseeing concern for the welfare of primitive peoples it is called upon to govern.

To Mr. Harold J. Coolidge, Executive Secretary of the Pacific Science Board of the National Research Council, whose office was home base for this Navy request mission.

To the Insect Control Committee for Micronesia, of the Pacific Science Board, Mr. Cyril E. Pemberton of the Experiment Station, Hawaiian Sugar Planters' Association, chairman.

To Mr. J. William Henry, American Vice Consul in Mombasa when we arrived there, and to Mr. Robert M. Taylor, American Consul in Nairobi.

To the many helpful and hospitable scientists and officials of British East Africa, especially Dr. E. B. Worthington, Scientific Secretary, Office of the East Africa High Commission.

To the many delightful little country hotels and to the Manor and Carlton Hotels in Mombasa, which together enabled us to travel so lightly equipped and so comfortably.

And to the South African Airways and the British Overseas Airways Corporation, which made such special arrangements for our flying home with a live insect and snail menagerie. In London we even adopted an unaccompanied shipment of live chameleons on their way to the Chicago Natural History Museum.

SCIENCE ON THE MARCH

A REVIEW OF PROGRESS IN TROPICAL MEDICINE

A RECENT article in "Science on the March" by Dr. Eugene H. Payne (October 1948) recalled a number of notable advances in tropical medicine that have been made during the past few years. It is the purpose of this report to supplement those remarks with a description of still further progress in this branch of the medical sciences. The particular tropical diseases to be considered are plague, yellow fever, amebiasis, and hookworm disease.

Plague: Plague is an acute, infectious, highly fatal disease characterized by fever, blood-stream infection, and hemorrhages into the skin, subcutaneous tissues, and internal organs. It is caused by an organism called *Pasteurella pestis*, and is little known by most people living under the protection of the United States. If we think of it at all, it is usually as an Oriental pestilence that periodically scourges the underprivileged peoples of the Far East, or as the Black Death, which ravaged Europe from the fifteenth to the seventeenth centuries. But plague is still an important disease today; in our modern times it is frequently rampant in India, China, Manchuria, Burma, Africa, Madagascar, and parts of South America. Furthermore, it is definitely not a disease entirely unknown to us in the United States. Although the epidemic that broke out in San Francisco in 1900 appeared to die out subsequently, the disease has assumed increasing significance, particularly during the past fifteen years. It will be of interest to look a little more closely into this situation in our own country.

Plague is primarily a disease of rats and other rodents and is transmitted from them to man by various fleas. During epidemics, it is principally the rat (brown sewer rat, or *Rattus norvegicus*, and the black house rat, or *R. rattus rattus*) that is involved. As a reservoir of plague infection it is more and more apparent, however, that certain wild rodents—in the United States especially the ground squirrel (*Citellus beecheyi*)—play an important part. All the recent human cases of plague in North America have resulted from association with such rodents, not from contact with rats. Fortunately, these deaths have been of only sporadic and occasional occurrence so far, but there are potentialities for an increase. The known area of infected wild rodents includes fifteen Western states. Surveys in these states have incriminated nearly forty rodents, including some fifteen species of ground squirrels, flying squirrels, wood rats, kangaroo rats, field rats, prairie dogs, chipmunks, marmots, and cottontail rabbits. The western badger, a mammal, has also been found infected with *Pasteurella pestis*. The demonstration that certain fleas that can transmit the disease are permanently established in Iowa, Ohio, Nebraska, Michigan, Washington, D. C., and other localities raises the possibility of wild rodent infection in these places too.

There are two principal factors by which plague is perpetuated in wild rodents. One is the occurrence of a low-grade, latent or hidden infection in the rodents which may last for as long as two months, during all of which time fleas can become infected. The other factor is the long period for which such infected fleas can remain infective for other rodents and for humans. Investigators have demonstrated that under certain conditions fleas can remain infective for periods up to five months and, in one experiment, for 396 days! Because of these facts, sporadic cases of human plague from contact with wild rodents and their fleas will undoubtedly always occur in the United States in spite of all efforts to eradicate them. With modern methods of sanitation in effect, however, there is little danger of a widespread epidemic.

Sulfadiazine has been found effective in treating human plague. The new antibiotic drug streptomycin is perhaps even more efficacious, but it is still too expensive for routine use. The present treatment of choice, until streptomycin becomes more generally available, is a combination of sulfadiazine and a serum prepared from rabbits by inoculating them with living but not virulent plague organisms. The serum has been developed by Dr. Karl Meyer at the University of California's Hooper Foundation.

Yellow fever: Yellow fever is another tropical disease that is little known to residents of the United States. It is of importance in Brazil, the Amazon basin, Colombia, Venezuela, and in its original African home—the Anglo-Egyptian

Sudan and Congo River Valley. It is an acute infectious disease caused by a filtrable virus and transmitted from person to person (or from animal to animal) by mosquitoes of the genera *Aëdes* and *Haemagogus*. There have been no cases of yellow fever in the United States since the early 1900s, owing to the control of the mosquito *Aëdes aegypti*.

In Brazil, widespread vaccination and mosquito-elimination campaigns carried on at first by the Rockefeller Foundation and then by the Brazilian National Yellow Fever Service have caused the disease to disappear from populated areas. But Brazil still has a yellow-fever problem in her vast jungle areas. In these locations, even when *Aëdes aegypti* is not present, persons whose occupation carries them into the forested jungle frequently acquire the disease. This is important because such infected individuals, by visiting a community where the mosquito *Aëdes aegypti* is present, can be the source of new outbreaks. This, as a matter of fact, has happened in Brazil and other South American countries along the northern coast. In our modern age of swift air travel, it is entirely possible that yellow fever, once so started, could be carried to the United States and other distant communities.

The exact nature or origin of this "jungle yellow fever" has long been debated, but evidence has accumulated which demonstrates the existence of the infection in other vertebrates and in arthropods. Recently, for example, it was conclusively shown in the Bahia Province of Brazil that four different species of marmosets, as well as other monkeys, have the yellow-fever virus. Jungle mosquitoes such as *Haemagogus spegazzini* presumably transmit the disease from monkey to monkey and, if the opportunity presents itself, to man.

As a result of such findings, there are some scientists who now believe that yellow fever may be essentially a disease of lower animals, with periodic outbreaks in man. If this should be true, the situation would be rather analogous to that just described for plague.

Vaccination continues to be a highly effective preventive measure in yellow fever. The so-called American "17-D" strain continues to be the vaccine of choice. During the course of recent surveys in Colombia, it was discovered that five years after vaccination with strain "17-D" 93 percent of the people still showed evidence of the effectiveness of the vaccine.

Amebiasis: The recent tropical medicine review by Dr. Payne remarked that, although some 10,000,000 people in the United States harbor the protozoan parasite *Endamoeba histolytica*, very few develop amebic dysentery or other forms of amebiasis. Speculation as to why some persons develop amebiasis and others do not is intriguing, but so far most of the questions remain unanswered. It is not known, for instance, why approximately 87 percent of reported cases are males and only 13 percent females. The role of alcohol consumption is not understood, either, but various surveys report 52–75 percent of patients to have had a more than average alcohol consumption over a period of time.

Nutrition is doubtless important as a factor in developing amebiasis, because E. C. Faust several years ago demonstrated that in general carbohydrates provide opportunity for the amebae to multiply, but animal proteins reduce this capacity. He found that in fresh raw liver, particularly, there is an unknown factor that tends to make the disease subside. In his experiments it was noted that amebiasis was controlled equally well whether the liver was given by mouth or ground up and administered in an enema solution. In spite of this work, physicians have not generally considered nutrition seriously when treating amebiasis with the more specific drugs available.

Another theory has been advanced that there is a close connection between certain bacteria and growth of amebae. For example, the presence of hemolytic streptococci seems to favor growth of the amebae, whereas *Lactobacillus acidophilus* impedes such growth. It is believed that the lactic acid of *Lactobacillus acidophilus* is the inhibiting substance. In one clinical trial of this theory, patients were given an anhydrous form of lactic acid, "Trilactic," as their only treatment. There was only moderate success, but sufficient to demonstrate that this was a likely factor in growth of amebae. The work is important because experiments such as this point the way for further investigation. Eventually we shall arrive at a treatment that will replace the not-too-effective drugs now in use. These drugs—emetine, diodoquin, chiniofon, and carbarsone—each have an important place in the treatment of the disease, but no one maintains that they have by themselves solved the problem of treating amebiasis.

One recent report regarding the transmission of amebiasis is of interest because it suggests that other means than "food, fingers, flies, fomites and water" may be important. Researchers in Talara, Peru, made cultures of the legs and intestinal contents of 100 cockroaches. No amebae were found in specimens from the legs of cockroaches; they were found, however, in 7 percent of the cultures from the intestinal contents. It was concluded that

food and utensils could therefore be contaminated by the amebae from the feces of cockroaches and that the common cockroach can be incriminated as a carrier of the parasite (at least in northern Peru). The high incidence of amebiasis in other tropical areas may also be partly due to heavy cockroach infestation, but it is not likely that this is an important factor.

Hookworm disease: Hookworm infection remains a serious public-health problem in the United States, as well as in the tropical portions of the world. It does appear, though, that the incidence is gradually decreasing as a result of mass treatment and repeated programs of health education. For example, in Florida, the first survey taken under the auspices of the Rockefeller Foundation in 1910 showed that 58.1 percent of of 6,155 persons examined had hookworms. In a recent study of 8,017 white school children, 40 percent had hookworm infection, but only one tenth of these had moderate or heavy intensity, Figures such as this are still much too high for a civilized country and indicate the need for an even more comprehensive program of better health along with hookworm control per se.

Hookworms live in the human body for five to eight years. Each worm sucks almost 1 cubic centimeter of blood from its human host each day. If only 10–25 worms are present, there is a loss of only 10–25 cubic centimeters of blood daily. If, however, 500 worms are present, there is too much blood loss to compensate for, and the individual rapidly develops an anemia. It is therefore of value for the physician to know just how many hookworms his patient may have when he first sees him for he will be better able to judge the seriousness of the infestation. This is done by counting the eggs passed in the stool of the individual. It has been ingeniously determined that each female hookworm produces 50 eggs per cubic centimeter of stool per day. By using this figure and applying it to equally ingenious short cuts in the egg-counting, the physician can tell approximately how many worms the patient is harboring. By repeating the counting of worm eggs after treatment has been administered, the exact effect of the treatment can be determined.

It should be noted that, although this article touches on a few high lights of the progress made recently in the field of "tropical" medicine, the diseases are not at all restricted to tropical areas. Amebiasis and hookworm disease are cosmopolitan in their distribution. Their incidence in the United States is high. Human plague, as pointed out, is rare in this country, but there is a huge wild rodent reservoir that keeps the disease going in an area of ever-increasing size in the United States. Yellow fever fortunately does not occur in this country now; however, it has flourished in the past in areas high up on the Atlantic coast and in the Mississippi Valley, and if there should be a serious break in our health control program, it is possible that yellow fever would again become a problem. In short, these diseases should really not be called "tropical" diseases at all; they are for the most part diseases that also occur in temperate climates but not to the same degree. There is a strong correlation between the occurrence of these diseases and the general hygienic conditions and state of nutrition of the people. If sanitation in the tropics were on a par with sanitation in the United States, such diseases would necessarily decline greatly in frequency. Progress is being made—real progress—sometimes with huge strides. But much remains to be done.

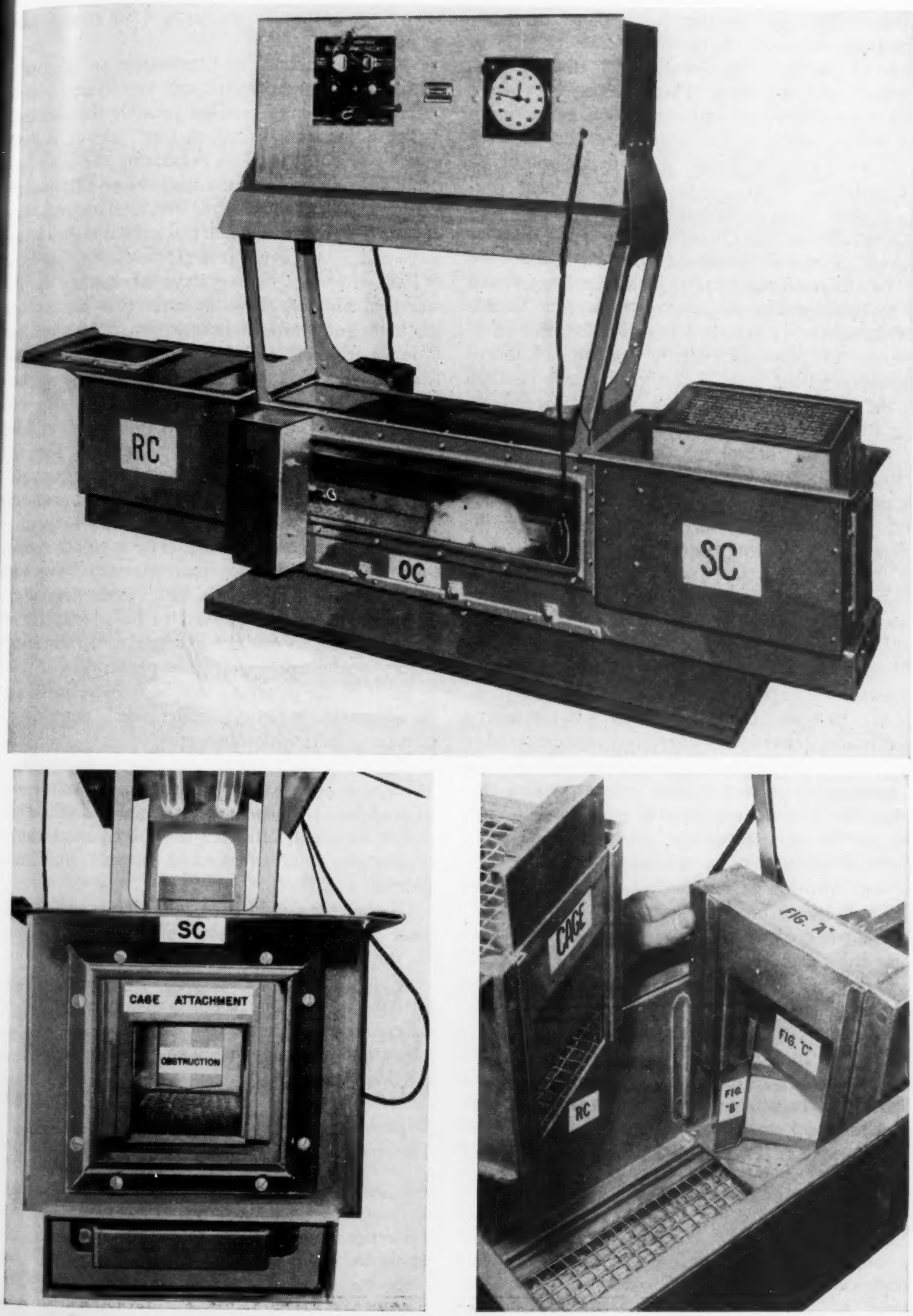
MARK T. HOEKENGA

Gorgas Hospital
Ancon, Canal Zone

TESTING REPELLENTS FOR RODENT CONTROL

CAN rats be used to aid man in his war against the rat? This is the question raised by the Office of the Quartermaster General. Of considerable concern to the armed forces during the war and to civilian economy as well is the tremendous destruction of food and materials by rodents. It was estimated that rodent destruction cost about $189,000,000 per year in the United States prior to the war. It has also been reported recently by the U. S. Fish and Wildlife Service that the rodent population in the United States is growing at a more rapid rate than the human population. These are impressive facts, and they indicate the urgency of methods for rodent control. To date no completely adequate method of rodent control has been developed. There are many rodenticides and repellents available to the desperate purchaser; there is no way of knowing which repellents are effective, however, although there is little difficulty in determining the effectiveness of rodenticides.

In many situations rodenticides or toxic baits



The Pittsburgh Obstruction Unit.

are desirable; on the other hand, there are many situations in which it is not feasible to employ traps or poisons. Repellents can be used in conjunction with toxicants. The repellent may drive rats from otherwise inaccessible places to more convenient ones, where poisons could be used with little risk or where the animals might be trapped.

In June 1946, a research program, sponsored by the Office of the Quartermaster General under a research and development contract, was started at the University of Pittsburgh by the Department of Psychology. The purpose was to develop "standard laboratory methods for evaluating the effectiveness of proposed rodent repellent substances furnished by the QMC." The project has resulted in the development of (1) a testing instrument, the Pittsburgh Obstruction Unit; (2) a method of motivation control for the rat; (3) a set of standard training and testing procedures for use in preparing and in selecting rats for repellency and barrier tests; and (4) a scaling technique adapted to evaluating tested materials.

The Pittsburgh Obstruction Unit has been described in the June 1948 issue of *The Journal of Comparative and Physiological Psychology.* The unit provides for the mounting of a physical barrier of any construction; in addition, it is possible to seal it for tests of vaporous materials or liquids. So far the research has been devoted to the testing of physical deterrents. A barrier when mounted in the unit blocks the rat's path to food. The barrier is mounted on a metal frame in such a way that two sides and an intervening angle project into the middle section of the unit facing the rat. The top and bottom of this passageway are contiguous with the barrier so that the animal cannot attack these surfaces.

Animals are prepared for training by restricting their caloric intake in such a way that a chronic hunger, with inanition, is produced. A standard set of barriers of progressive difficulty is presented to each animal over of period of twelve days. Following this, the rat is tested with a standard barrier for twelve more days. Both trapped wild gray and laboratory-raised albino rats have been used in equal numbers. Both males and females were used, and grays and albinos were matched for weight so that comparisons of the groups could be made.

The obstruction unit contains an electronic circuit with a photoelectric-cell switch and a chronoscope. This circuit makes possible the measurement of the animal's attack time, and it is these records that are used in evaluating the rat's performance on the standard barriers and the rodent resistance of candidate materials. The recording of time is terminated when the animal makes a hole large enough to permit it to get through to the food.

Following the twelve days of testing on the standard barrier, those animals that were above the average in rate of penetration were given additional training and then employed in tests of treated materials. In all tests of treated materials a standard untreated barrier was also used as a control. Most of the treated barriers have been supplied to the project by the U. S. Fish and Wildlife Service; some, however, have been prepared by the project personnel from materials suggested by the Wildlife Service as a result of preliminary screening tests. The method appears to work well, and no basic changes have been necessary in the approach. In all cases none of the materials tested has proved to be sufficiently rodent-resistant to prevent a single well-trained and highly motivated animal from penetrating it.

Some of the materials that have been tested are: dithiobiuret; *n*-phenyl maleimide; pentachlorophenor; Onitrochlorobenzene; dodecylamine hydrochloride; Vinylseal (A-70); Piccoumaron (452-S); latex; bis (5-chloro-2-hydroxyphenyl sulphide); alpha-picoline picrate; diethylamine picrate; sodium silicate; duco lacquer (white); copper napthenate; processed tung oil; and Lucite (acrylic resin).

Of the many wild gray and albino rats used in these studies, comparisons of mean attack times on the standard barrier indicate that there is a very small difference between the wild and domesticated rats and that there is also a negligible sex difference. For these reasons it appears that any hardy and vigorous strain of rats can be adopted for this type of bioassay.

LAWRENCE M. STOLUROW
Department of Psychology
The University of Pittsburgh

BOOK REVIEWS

EXPERIMENTAL PLANT SCIENCE

Vernalization and Photoperiodism. A Symposium. A. E. Murneek and R. O. Whyte, with others. vii + 196 pp. Illus. $4.50. Chronica Botanica. Waltham, Mass. Stechert-Hafner. New York.

THIS symposium consists of fourteen papers by several authors who have been active contributors in the fields represented. In general, the various topics treated are summarized, sometimes with attempts at critical evaluation of the data, and sometimes not. Much of the evidence presented still leaves any interpretation of it on a controversial basis. This is especially true of the chapter that deals with vernalization.

The approach in many of the papers is from the viewpoint of experimental ecology. Few detailed data which deal with an analysis of the problem of photoperiodic response from the viewpoint of cellular physiology or biochemistry are presented. A brief presentation of some such data are given in the paper on thermoperiodism. In some cases the few data which are given are dismissed as irrelevant or are mutually contradictory.

Nearly all the papers postulate the presence of a hormone which, although not yet isolated, is presumed to account in some fashion for many of the results recorded. The evidence adduced is of interest and may yet lead to the isolation of some specific substance or substances, but, since present-day knowledge on the physiological cellular response to hormones is meager indeed, any explanation on a hormonal basis results principally in an attempt to present a basic explanation of one unknown in terms of another.

Calling attention to the responses of plants to alternating or nonconstant conditions rather than to a constant environment is of great service to those who attempt a more detailed comprehension of plant behavior. Many more studies and observations of that type are needed. Such periodic response may well be found eventually also in relation to variations in moisture supply, nutrient supply, and various other environmental factors to which successful horticulturists and plantsmen have given serious attention for many generations.

The symposium aggregates many observations of value to those who deal with plants on an economic basis, but offers less to the physiologist interested in plant functions or processes, especially from the standpoint of cellular physiology or biochemistry. Although changes in photoperiod may be used as an ecological factor to bring about reproductive phases in some plants, it offers no universal explanation; there are too many plants that are day-neutral or nonsensitive. Instead of casting aside as irrelevant the few cases in which a nutrient or internal relationship has been experimented upon, and the vast amount of field experience which bears on this point, it would be more profitable to carry on many more detailed experiments relating to such possible relationships under various ecological conditions, and with plants sensitive in varying degrees to such imposed variable environmental conditions. There seems to be no basis for any universal generalization as yet that photoperiodism is the sole controlling factor of the vegetative or reproductive states in plants.

E. J. KRAUS

Department of Botany
The University of Chicago

THE HOPKINS

The Story of The Johns Hopkins. Bertram M. Bernheim. xi + 235 pp. Illus. $3.50. Whittlesey House. New York. 1948.

THIS book should be of great interest not only to medical graduates of The Johns Hopkins but also to anyone interested in the progress of medicine and medical education in the past sixty years. Dr. Bernheim is himself a graduate of The Hopkins—Class of '05—and has lived in Baltimore, where he practices surgery, ever since. When he went to medical school the idea of medicine, not as an apprenticeship but as a postgraduate study with especial stress on theory and research, was still quite new in this country, and he had the privilege of working under all four of the great doctors and pioneers in this type of teaching who made the name of The Hopkins Medical School famous all over this country—and indeed over the whole medical world.

He traces the growth and development of the school from its very inception and earliest years down to the present, discusses and evaluates the share the various members of its staff have had in shaping its policy, and relates the new things in medicine that were developed by the research work encouraged by them. He shows how the policy of the surgical department led to the growth of the other famous Baltimore hospitals and traces the history of the Hopkins unit and the influence of Hopkins doctors in World Wars I and II; he does not neglect the various branches, such as the Phipps Clinic, the Brady, the Wilmer Institute, the Welch Institute of the History of Medicine, and the School of Nursing. The last chapter is devoted to a discussion of the future of the institution. As Dr. Bernheim writes in a very vivid, easy, and colloquial style, and points up his narrative with a

wealth of entertaining and pertinent anecdotes, the book is delightful reading as well as being most interesting and informative. Dr. Bernheim's conclusions reflect the serious thought that he has given to his subject.

There is only one criticism that can be made—Dr. Bernheim, as a surgeon, has given full credit to the achievements of the surgeons and internists, but he evidently failed to realize the great influence that Dr. John Howland has had on the development of pediatrics and his role in training the present-day leaders in this field.

WILBURT C. DAVISON

School of Medicine
Duke University

MINERALS AND PLANTS

Mineral Nutrition of Plants and Animals. Frank A. Gilbert. 131 pp. Illus. $2.50. Univ. of Oklahoma Press. Norman.

THE mineral nutrition of plants and animals is dealt with competently and briefly, almost in summary form. A short discussion at the end suggests conclusions about the importance of the elements in soil fertility and human nutrition.

After a very brief historical introduction and a short chapter on the classification of the elements significant in nutrition, the author takes up each element individually. These compact statements make up most of the book. Ten pages are given to phosphorus, eight to calcium, and smaller sections to magnesium, potassium, sulfur, iron, copper, cobalt, manganese, zinc, iodine, boron, molybdenum, aluminum, silicon, sodium and chlorine, fluorine, and arsenic, lead, and selenium.

The book might have had a little wider usefulness if some material had been included on the occurrence and availability of the nutrients in soils, especially as a basis for the final chapter. In this chapter the author may somewhat oversimplify the problem of changing the mineral composition of plants with fertilizer. On some soils the content of certain mineral elements in plants growing on them can be increased by adding ordinary fertilizers containing the elements. But often this cannot be done, at least significantly. The problem of improving the nutrient quality of food crops through fertilization and other management is almost unbelievably complicated. Fortunately, research is going ahead in this field.

For those who want a brief, authoritative summary of the functions of elements in plants and the most significant relationships to animal nutrition, this is an excellent book. It is dignified, yet easy to read. The book contains a valuable bibliography of some 329 references. It is well printed and properly indexed.

CHARLES E. KELLOGG

Bureau of Plant Industry, Soils and Agricultural Engineering
USDA
Beltsville, Maryland

OF SHIPS

The Story of the Ship. Charles E. Gibson. xiv + 272 pp. Illus. $4.00. Schuman. New York.

The Merchant Ship: Design Past and Present. G. S. Baker. 159 pp. Illus. 12*s*. 6*d*. Sigma Books. London.

GIBSON has written an outstanding book. It is not only a story, but a history, of how the great vessels of today developed from the first primitive floating log. Mr. Gibson, himself a sailor who loves and understands ships, has collected all the lore and studied all the laws of shipbuilding through the ages, from 4000 B.C. to the present day. He traces with a light touch the gradual improvements upon the plank and sail through the Egyptian and Assyrian eras, with their early navigational instruments, to the merchantmen of Phoenicia, who sailed from Cadiz to Carthage with their rich cargoes, on through the Greek mastery to the rise of Rome and the beginnings of Western ascendancy. Each civilization left its mark upon the ship until in the fifteenth and sixteenth centuries the great navigations of Columbus and the Cabots, of Hawkins, Magellan, and Drake, opened up the vast Atlantic and Pacific to the ship, with guns and gunpowder changing its design again in the sixteenth century.

"Canvas and cannon," as Mr. Gibson puts it, made every vessel into a warship, and during the Middle Ages any merchant ship could and did so function. He shows very clearly when and why the division between merchantmen and warships was made and how competition mothered the necessity for steam until at last it triumphed. All the changes in design involved in this evolution are given accurately enough for the student and mariner and yet are easy enough for the layman to assimilate. Ship design from canoe to *Queen Mary* is described, and warship design from the galley to the aircraft carriers of today. Methods of propulsion from oars to atom are scientifically and professionally explained, and the reader is given an insight into the future by this exact and interesting study of the past and present.

I read the book with delight, for we have all too few books that link the development of the ship with the development of mankind. If you have a speck of salt in your make-up, you will sense the drama of the ship's growth; if you are a student, you will learn about shipbuilding painlessly and profitably; if you are a ship's officer, you will find within these covers, written in your own language, all the romance of the decks you tread; and if you are a scientist, you will approve the painstaking detail with which Gibson has done his research. Every reader will enjoy *The Story of the Ship,* which is beautifully illustrated by twenty-seven excellent plates and contains a good nautical glossary. As a seafarer, I heartily approve it, as an educator heartily recommend it. I sat up half the night to finish it because it was too interesting to lay aside.

In *The Merchant Ship, Design Past and Present,* Dr. Baker has written an excellent book both for the student and the general public on the evolution of ship design from the Neolithic age to the present-day ocean giant. He has written well from his own extensive knowledge, and his information is detailed and accurate enough for the professional ship's officer to con, or for those who stay at home to enjoy. There is a great need for books of this type to satisfy the many questions in the layman's mind as to freeboard and bilges, tonnage and displacement, gunwales and sheer strake, and the like.

Dr. Baker explains it all in layman's language and in 160 pages covers the whole field of past and present ship design in intelligible words and with an eye to the future. A chapter on the ship at sea explains the various motions of the vessel—rolling, pitching, heaving, yawing, etc.—and how a ship is designed to withstand these stresses.

Speed, together with its effect on design and its relation to economy, is well defined and the relative merits of each method of propulsion compared. In the final chapter Dr. Baker tells of modern ship types, how they are constructed, launched, and tested on trials.

Vice President of the British Institute of Naval Architects, Dr. Baker is a world-wide authority on ship design. His book is a splendid contribution to the literature of shipbuilding and, being technical but not tedious, has an appeal to all readers who want to find out what makes the ship tick. I recommend it highly to librarians, to nautical schools, to mariners in all stages of development, to travelers about to take an ocean voyage, to naval architects, and to all men and women who like to go down to the waterfront and watch the ships go by—and to all thoughtful students of human affairs who realize how much our nation's safety and prosperity depend on shipping.

The book abounds in fine illustrations and possesses an excellent glossary of nautical nomenclature. Professionals and amateurs alike will enjoy it and benefit from reading it.

GORDON MCLINTOCK, REAR ADMIRAL, USMS
U. S. Merchant Marine Academy
Kings Point, New York

FLORIDA BIRD LIFE

Flight Into Sunshine. Helen G. Cruickshank. cxxi + 132 pp. $5.00. Macmillan. New York.

HELEN G. CRUICKSHANK and her photographer husband, Allan, have created a monument to themselves as naturalists, and a tribute to the National Audubon Society, protector of birds. In *Flight Into Sunshine* they have abundantly attained their expressed desire, "to pass on a little of the amusement and excitement" of their bird experiences in Florida. They have done more. *Flight Into Sunshine* records hitherto unknown facts concerning the nesting and other habits of many Florida birds. These are smoothly blended with interesting narrative and vivid descriptions of the sights and sounds of Florida's tropical wilderness.

The first chapter concerns the trip by car from New York, the equipment required by naturalist-photographers in the field, and a few historical high lights of the areas to be visited. Each of the remaining eleven chapters treats, in a highly interesting manner, a single species as studied and observed at one or a few specific locations. Typical chapter titles are Florida Cranes on the Kissimmee Prairie and Anhingas at Paradise Key.

In addition to precise information on the nesting habits of Florida birds, *Flight Into Sunshine* contains many interesting accounts of the authors' personal experiences. One of these, with a five foot, eleven inch cottonmouth, solved the mystery of destroyed glossy ibis nests. By dissection it was revealed that the reptile had swallowed five ibis and Louisiana heron eggs, a very large young American egret, and an adult glossy ibis. To the authors themselves "it seemed almost incredible that one cottonmouth moccasin could hold so much." Many naturalists will envy Allan Cruickshank the experience of watching a Florida crane hatch. The behavior of the brooding birds which culminated in their covering the young and the remaining unhatched egg with grass had probably never before been witnessed or recorded.

One hundred and twenty-one superb photographs grouped in one section complete the volume. These, the product of expert skill and endless hours of patient effort, multiply the value of the book manyfold.

E. J. WOOLFOLK
U. S. Forest Service
Washington, D. C.

EXPLORING THE FAR NORTH

To the Arctic! (Rev. ed.) Jeannette Mirsky. xxi + 344 + xviii pp. Illus. $5.00. Knopf. New York.

THE opening sentence of Stefansson's introduction to this book asserts that it "is both fascinating to read and the best history of northern exploration so far written." Both statements are true—indeed, who would doubt them, coming from the supreme authority on Arctic matters—but we wish to qualify each of these assertions. In our opinion, the author dwells unduly upon the romantic, the adventurous aspects of the expeditions she chooses to describe: hence the reader's fascination does not derive from the subject matter itself, the gradual unfolding of the Arctic region; it does not derive from the pleasure experienced when viewing the expansion of our scientific horizons, but rather from the somewhat artificial emphasis on the dangers and hardships experienced by some of the explorers. And if this partial account is in fact the best history of Northern exploration so far written, then the task of writing a first-rate, comprehensive, and authoritative account remains to be done. Such an account would surely

not omit from its index the names of Waldemar Jochelson and Waldemar Bogoras, authors, respectively, of the standard monographs on the Koryak and the Chukchee, and foremost among ethnologists who have ventured into northeastern Asia. It would at least mention the great Finnish explorers of Siberian peoples and languages—Castrén, who studied the Lapps of Scandinavia and the Kola Peninsula from 1841 to 1844, and who visited the Samoyeds throughout Siberia in 1845–49; Ahlqvist, who went to the Voguls and Ostyaks in 1858; and Donner, who carried on where Castrén had left off. An account that aims to be a history of Northern exploration cannot leave out the story of the great Hungarian explorers either: Reguly, Munkácsi, Pápai. All these, and numerous other expeditions, are not even mentioned in this book. The author admits these limitations herself: she deliberately omits the data that really are of scientific interest and relevance—references to the peoples who inhabit the Arctic, "the study of ocean currents, weather conditions, flora and fauna, experimentation with crops and domesticated animals, settlements, transportation routes, mining, lumbering, and so on."

In other words, this is a popular book written for the layman. We do not mean this disparagingly at all, but wish merely to call attention to the fact that such is the "best history" of its kind, and that this condition ought to be remedied in view of the tremendous and ever-increasing military and economic importance the Arctic region has come to bear in the twentieth century. We need an adequate Arctic guide and reference book: perhaps Stefansson himself can be prevailed upon to write it!

THOMAS A. SEBEOK

Department of English
Indiana University

CONSIDER THE HEAVENS

The Stars Are Yours. James Sayre Pickering. x + 264 pp. Illus. $3.95. Macmillan. New York.

SPACE is practically 99 percent mystery," according to Professor Pickering, who then solves, in the simplest possible language, some of that mystery for the layman. He even provides, unwittingly, source material for "science fiction" in such statements as: "Not only did Jupiter destroy the parent planet (of the asteroids), but he is holding captive some of the spoils of his ancient victory." But the purpose of the book is to help us become acquainted with the stars that twinkle so brightly in our sky and differ in aspect from season to season.

It begins with our own star, the sun, and continues out into space with the planets, including earth, the comets, the meteors, the nebulae, and the constellations. The discussions are full of facts such as distance and speed of travel and size, full of the theories as to the origin of the solar system and life on the planets, full of answers as to why the sky is blue and why such stars as Betelgeuse vary in brilliance. There are the fascinating "white dwarfs," the novae, and the dark banks of cosmic dust. Much of the book is taken up by charts of the heavens, in which north is at the bottom of the page because they are to be held over the head for study. These charts are arranged according to "culmination date" or the date when the exhibited constellations are as portrayed. In addition, there are twenty-three beautiful and awe-inspiring photographs of the solar corona, of the rings of Saturn, of the great nebulae. There are lists of the constellations, star tables and a list of star names, and a bibliography.

In fact, there is everything in the book necessary to the beginner in astronomy. It is equivalent to a year's course at college or university. Moreover, the writing is pleasant, with dry humor but not dry scientific data, and enlivened by graphic figures of speech. "There we are—and there are the stars. They are among the most beautiful, the most interesting and the most mysterious objects in our lives. All that we have to do to partake of their beauty and their eternal mystery is to step out of doors" with this book in hand.

MARJORIE B. SNYDER

Washington, D. C.

NATURE'S CHRONOLOGY

Days Without Time. Edwin Way Teale. 283 pp. Illus. $6.00. Dodd, Mead. New York.

THOSE who follow that genre of literature we call nature-writing are coming to regard a new book by Edwin Teale as an event. First of all, he is a good writer; he has something fresh to say about nature and says it directly, simply, and authoritatively; he can be learned without being pedantic, and dramatic without being sensational. Second, he is a photographer par excellence, and his close-up views of his subjects—milkweed, skunk cabbage, trees, grasshoppers, butterflies, insect eggs, birds, cats, etc., etc.—are superb.

The Teale combination of text and photographs is a thing of beauty and great satisfaction. This happy result has been abetted by what seems to us a greatly-to-be-emulated attitude on the part of the publisher, who has seen fit to treat both the text and the illustrations in a generous manner and has exerted obvious effort to see that the final product shows evidence of some of the niceties and potentialities of the printer's craft. The printing of the half tones is especially good. (Perhaps a few petals of this bouquet should fall into the basket of the Vail-Ballou Press, Inc., of Binghamton, New York, who actually printed the book.)

The essays that make up *Days Without Time* are on a miscellany of subjects in the realm of nature—plant and animal, human and nonhuman. A characteristic that adds variety to Mr. Teale's style is his way of drawing not only from his own wide observations and experiences as a naturalist, but also from those of others, evidencing a wide reading in natural-

history literature and a desire to enrich his writing with a laudable eclecticism. As the English essayist C. E. Montague once put it, there are many persons "going up and down this well-read world with literary luggage so meagre that it is hardly worth putting in the rack, not to speak of the van." Edwin Way Teale is not one of these. He has many "friends on the shelf," and he loves to pull them down.

PAUL H. OEHSER

Smithsonian Institution
Washington, D. C.

COMMON DENOMINATOR

Marching with the Grasses. Raymond J. Pool. xii + 210 pp. Illus. $3.50. University of Nebraska Press. Lincoln.

WITHIN the compass of this small book, the author has sketched in outline the origin, distribution, and utilization of the wild and cultivated grasses of the world in their connection with man's social and economic progress to the present state of civilization. About 100 pages are devoted to the discussion of the place of wheat, rice, corn, barley, oats, rye, sorghums, millets, and sugar cane as sources of food for man and animal. In the workaday world, these plants are not commonly thought of as grasses, but from a botanical standpoint they are true grasses.

In the remaining 90-odd pages, numerous tables, maps, lists, and descriptive materials are presented regarding the location and extent of the chief grassland areas of the world, with special mention of the important grass species for meadows, pastures, and ranges in the different countries.

In the history of agriculture, the herder preceded the farmer. Among domesticated animals, herbivorous species (cattle, sheep, goats, horses) were first in importance. Grass was their staff of life, at first the native grasses of the prairies and mountainsides. Gradually man selected the most promising kinds of grasses and began improving them in the direction of more suitable human food, the cereals, till today, when man lives directly, or indirectly through meat products, on grass. So it has come about in the past two decades that the tide in agriculture has set strongly toward grass farming. The author shows how this trend is manifesting itself in all parts of the world. Grass helps, as perhaps nothing else can, in preserving the fertility and proper physical structure of soils, and is also a most effective means of anchoring the soil against the erosive action of wind and water. Grass farming naturally stresses livestock, and that in turn makes necessary an increase of the grass coverage and a decrease in the area of farmland left bare and exposed to erosion.

Long-continued experiments aimed at determining the species of grasses most suitable for hay, pasture, and range, and for various climatic conditions, have provided lists of grasses to be recommended for these different conditions. The author has selected representative examples of grasses in these groups for description of their special qualities and the required conditions for their best development.

A special chapter deals with the use of grasses in soil conservation in different parts of the United States, and on methods of reseeding the Western rangeland where the grass carpet has been worn thin. Nor is the problem of grasses for lawns, parks, and golf courses neglected. Grasses have found their way into an almost endless list of uses: for hedges, ornamental decorations, matting, sandals, hats, baskets, brooms, paper, perfumes, roof thatching, and so on.

Not all grasses are looked upon with high esteem. A few of them are quite generally considered weeds. Crab grass has exhausted the patience and ingenuity of many a lawnmaker; sandbur is a bane to man and beast; foxtail and Johnson grass are not welcome everywhere. But it is well to be reminded from time to time of the transcendent importance of grass, as the author has done in this book.

E. V. WILCOX

Washington, D. C.

EXOTIC CULTURE

Island of Death. Werner Wolff. 228 pp. Illus. $7.00. Augustin. New York.

EASTER ISLAND, for a land of its size, has been the subject of its share of books and articles. Isolated beyond most inhabited islands, and with the added attractiveness of great stone statues and a mysterious writing, it has for many years been the perfect subject for studies serious, romantic, and speculative. This latest addition to the literature of Easter Island is a controversial book. Dr. Wolff, who has an active and inquiring mind, brings his knowledge of psychology to the aid of ethnological science in an attempt to solve some of the baffling problems of Easter Island culture.

The first chapter is devoted to a summary of the knowledge of the island and the culture of the people. Throughout the summary, as throughout the book, there are numerous comparisons, of a speculative nature, with Oriental and Central and South American cultures. Section II describes the various types of stone and wooden statues found on the island and discusses their symbolism and significance, and their relationship to the "death cult" and the "bird cult." The author distinguishes two types of stone "idols" and finds that all statues, both stone and wooden, have in common identification with a being, an object, or a force. In a later section (VI) after relating the various theories attempting to explain how the huge stone statues could have been moved from the workshop in the crater of Rano Raraku to the sites where they stand, Dr. Wolff comes up with the extraordinary theory that they may have been ejected from the crater by a volcanic eruption. He admits, however, that this theory, which fits in with the native explanation of magic transportation, of "giant-statues flying

through the air like ghosts, seems to resemble a fantastic dream."

On the basis of the native Metoro's readings of the tablets to Jaussen, Dr. Wolff has attempted to decipher some of the tablet writing. His method and interpretations are set forth in detail in Section III. Section IV contains a summary of theories about the origin of Easter Island culture. Numerous similarities and parallels between Easter Island on the one hand and Polynesia, Melanesia, North and South America, the Orient, and Egypt on the other are noted. The Egyptian similarities are further pursued in the next chapter, which is devoted to the hieroglyphics. On this subject the author concludes in part (p. 143):

> I found a large number of Easter glyphs and glyph-groups which have notable similarities to certain Egyptian glyphs. Since the meaning of certain glyphs is known and since the graphic similarity accompanies the similarity of meaning, I feel justified in believing that in cases promoting this graphic similarity—where the significance of the Egyptian hieroglyphics is known—the meaning of the island glyphs may be guessed from the corresponding Egyptian sign.

The book concludes with a chapter on the folklore of Easter Island, finishing with a discussion of logical versus symbolical thinking, the latter, according to the author, typifying that of the Easter Islander.

Dr. Wolff has written a stimulating and thought-provoking book containing a number of theories and suggestions with which few specialists on Polynesia will agree. The book is well designed and handsomely printed, and the publisher is to be congratulated on a fine piece of bookmaking—something all too seldom found among modern anthropological publications.

Ernest S. Dodge

Peabody Museum of Salem
Salem, Massachusetts

HYDROLOGY

Rainfall and Runoff. Edgar E. Foster. xix + 487 pp. Illus. $9.00. Macmillan. New York.

In *Rainfall and Runoff* the author has provided a signal service by bringing together in one volume the story of the developments that have taken place in the field of hydrology. The work covers a vast area, ranging from meteorology through the utilization of hydrological data. It is valuable in pointing out the developments that have occurred, in indicating where the student and engineer should go for more detailed information on any particular phase of the subject, and in advancing the use of statistical methods in the utilization of hydraulic data.

The limits of water in location and in amount available for use by mankind are unfortunately unpredictable with any degree of accuracy. Records available pertaining to precipitation and runoff are of extremely short duration when measured in terms of even the recorded period of civilization. As the length of records increases, however, it appears that droughts become more severe and storms and flood occur in greater intensity and are of greater duration. Statistical approaches are handicapped by having to consider very uncertain limits and relatively brief records. These factors should not discourage the use of such methods, but the engineer should keep in mind the limitations involved.

The book places a great deal of emphasis on the use of the H. Alden Foster and Allen Hazen approaches in the treatment of hydrologic series for indicated frequency of occurrences. It would have been well also to give some consideration to the approaches used by E. J. Gumble, a recognized leader in the use of the classical theory of the calculus of probability as related to studies of frequency. There also might have been included reference to the proposal made by Marion Clawson with respect to determination of the coefficient of variability-sequence. The author is to be commended for his reservations regarding the station-year method.

It is necessary that all the tools available to the practicing engineer should be utilized in planning the best use and conservation of our water resources, both above and below the ground surface. Mr. Foster's treatise is important in that it indicates nearly all the tools that have been developed and the limitations of use. The practicing engineer working on hydrology, however, needs to deal with more specific and detailed examples than are given in the book. The excellent and comprehensive bibliography makes such opportunity available.

The inclusion in the book of the chapter on ground water is particularly timely. The various geologic definitions in relation to ground water should be useful in directing the attention of engineers to the relationship as between geologic forms, ground-water storages, and replenishments. Additional information and research in this very important subject are needed.

There is, appropriately, a good discussion of evaporation in arid and semiarid areas. Evaporation in humid areas is also important. With respect to evaporation in such areas, the stream flow as recorded below any proposed reservoir has already been reduced by a very considerable loss of moisture from the reservoir area in the form of transpiration and evaporation. Under these conditions, the net loss of useful water from the reservoir is the difference between the gross evaporation from the reservoir surface as determined from pan evaporation and the existing loss from transpiration and evaporation that has already been accounted for in the stream-flow records that are used to determine the quantities of useful water available. Large errors in estimates of reservoir evaporation can be made by not taking account of these predevelopment transpiration and evaporation losses. Future revisions of the book might well include consideration of the later work of C. W. Thornthwaite.

The author has undoubtedly put a great deal of hard work into the preparation of this book, and it is

unfortunate that the price could not have been set at a figure more nearly within the reach of the average student and engineer.

E. ROBERT DE LUCCIA

Federal Power Commission
Washington, D. C.

LOGIC AND METHODOLOGY OF SCIENCE

The Limits of Science. Leon Chwistek. Trans. from the Polish by H. C. Brodie and A. P. Coleman. lvii + 347 pp. $6.50. Harcourt, Brace. New York.

THE scope of this work is indicated by the subtitle, *Outline of Logic and of the Methodology of the Exact Sciences.* The official title seems unfortunate, suggesting, as it does, just another humanistic diatribe against science. The book is anything but that. Much of it is heavy reading on—to give the main chapter headings—The Limits of Sound Reason; The Development of the Concept of Number; The Elementary Concepts of Semantics; The Calculus of Propositions; The Theory of Classes; Foundations of Rational Metamathematics; The Fundamental Concepts of Mathematical Analysis; Problems of the Methodology of the Exact Sciences; and The Problem of Reality. Quite a program for 347 pages. Chwistek's work on logic, semantics, and the foundations of mathematics and of physical science has long been familiar to specialists in such fields, especially to those who can read Polish. This translation will remove at least the linguistic barrier to an understanding of Chwistek's subtleties.

In the Introducation to the Introduction proper, it is remarked that "Unfortunately . . . Chwistek uses a vocabulary and symbolic apparatus different from that of other philosophers and logicians." This is not peculiar to Chwistek, as may be verified by glancing through recent papers on symbolic logic. Philosophers, of course, have been talking to themselves for centuries; but that is no reason why logicians should attempt to emulate them. If there ever is an international congress of logicians, one item on the agenda might be an effort to agree on a common symbolism for those things that are common to the works of at least three symbolic logicians. The present situation is similar to, but worse than, the Babel in vector analysis before some of the private notations of various writers were swept into limbo about thirty years ago.

For those who do not care to master the symbolism, there is much interesting historical material attractively presented here. There also are occasional asides that no doubt will appeal to the philosophically minded. For example, "At the basis of the problem of time lies the longing for immortality and the fear of death." How does anybody know that?

E. T. BELL

California Institute of Technology

UP TO DATE

Readings in the Physical Sciences. Harlow-Shapley, Helen Wright, and Samuel Rapport, Eds. xii + 501 pp. $3.00. Appleton-Century-Crofts. New York.

THIS book contains a number of articles designed to present to the reader the modern scientific picture of the physical world. In selecting these articles the editors have laid emphasis upon contemporary writers because of the rapid advance in the physical sciences in recent years. Early scientific workers have not been entirely neglected, however. We find in the book Galileo's account of the discovery of the satellites of Jupiter with his new telescope, and an extract from the epoch-making article by Copernicus "Concerning the Revolutions of the Heavenly Bodies." We also find extracts from Newton's *Principia,* and letters by Franklin describing his kite experiment and the effects of a Leyden jar discharge on the human body.

The articles contained in the book are classified under six headings: Science and the Scientific Method, Astronomy, Geology, Mathematics, Physics, and Chemistry. In each class there is a general introduction by the editors and a copious bibliography of modern works on the subject. The reviewer was particularly pleased to find that the mathematical bibliography includes E. A. Abbott's *Flatland: a Romance of Many Dimensions,* a book which well deserves being rescued from oblivion.

That the book is quite up to date may be seen from the fact that in the section on physics there is included a long extract from Smyth's official report on *Atomic Energy for Military Purposes,* and that in the section on chemistry there is an article by Gibbons on synthetic rubber—a wartime product that is apparently here to stay.

The reviewer has given particular attention to those articles not in his own specialty, and has found them generally well written and easy to understand; and for this reason he feels justified in recommending the book as successful in the purpose for which its editors designed it.

PAUL R. HEYL

Washington, D. C.

CORRESPONDENCE

OLD

I am a member of the AAAS but do not subscribe to THE SCIENTIFIC MONTHLY. However, I happened to see the article by Bruce Old entitled "On the Mathematics of Committees, Boards, and Panels" in the issue of August 1946. . . . This article was most entertaining and edifying, because it reflects much of what goes on at some of the meetings of committees and boards I have attended. If the article is available as a reprint, I should be most appreciative of a copy.

BERNARD H. FOX

Department of Psychology
The University of Rochester

NEW

Perhaps you will be interested in an experience I had recently. I loaned to a colleague of mine the December 1948 issue of THE SCIENTIFIC MONTHLY so that he might read Dr. Knudson's article on "Sound Waves and Rhythms," . . . We are both working occasionally in the field of sound. He returned it in two days and asked for another issue because he liked the first one. In a few days he came back for two more, and I am afraid he will want to read all the 1948 issues. He states that it is the best scientific magazine of its type he has come across, and he would be pleased to consider membership. . . .

C. J. KRIEGER

San Diego, California

AID TO BEILSTEIN WORKERS

I appreciate the opportunity of calling to the attention of the members of the American Association for the Advancement of Science a campaign of the Philadelphia Section of the American Chemical Society to raise $2,500 to purchase food packages for the Beilstein Editorial Board. This worthy cause should appeal particularly to chemists who are members of the AAAS.

Although Beilstein, Gmelin, and other chemical compendia are produced in Germany, they are of international character, and their continuation is vitally important to chemists.

Contributions should be sent to Dr. William H. Hugh, treasurer, Philadelphia Textile Institute, Pine and Broad Streets, Philadelphia 2, Pa. Each donor will know exactly to whom a particular package paid for is finally sent. Here is an opportunity for the scientists of the United States, and particularly the chemists, to demonstrate a willingness to assist fellow-chemists in dire need. Without such assistance it is very likely that the work on Beilstein and other chemical compendia will cease—or at least be delayed considerably. For both selfish and unselfish reasons financial assistance is desirable.

WALTER J. MURPHY

Industrial and Engineering Chemistry
Washington, D. C.

LABORATORY MOUSE

Abhorred, damned, and hunted,
Timorous, persistent, prolific,
Symbol of uncleanliness;
Pulsing, sniffing, prying,
Gnawing, befouling, multiplying;
Furry, silent,
Once suspected of spontaneous generation
From rags and corn;
Commiserated by the tender, earthy poet—
Up through the years, mouse, you have come with us,
An unwilling sacrifice on the edge
Of a widening circle of knowledge;
Invaluable to searchers sounding the uncertain dark
To build greater safety for man and all his animals—
Except you!

Here you are now, mouse,
Bred up from nocturnal noxiousness in must and dust
To ordered living in tended rooms,
On airy shelves,
In round glass houses,
In wire apartments;
A quart of milk a day to 150 of you,
Protein pellets in wire mangers,
Bread and cake, good food and bad, and doubtful—
Whatever research requires,
But always in ease and with a gambler's chance at security—
For what happens to you may be the long-sought answer.

Your tail is a handy hold to dangle you
While man reads the record from your knife-notched ear,
You are favored more and more as his circle
Widens into the border of the cold unknown.

You are the elite of the rodents—
The squirrel is an irritable chatterer;
The groundhog is shot with a "22" or gassed in his burrow
As a clumsy clover thief;
The prairie dog is poisoned for his industry and prolificacy.
You, mouse, were created convenient, omnivorous, and economical
Of food and space and time;
You compass a human lifetime for, perhaps, a dollar;
You eat as man does;
You share his diseases;
Now you face outward with him on the ever-widening front.

Little mouse, you're a happy tool,
Why should I say
"Don't be a fool?"

CHARLES E. GAPEN

Chevy Chase, Maryland